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Deep Neural Network Work-Flow and Applications

~ Instance @ SBN, Toward ArgonCUBE and DUNE ND ~

Kazuhiro Terao

SLAC National Accelerator Laboratory

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Deep Neural Network Work-Flow and Applications

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Outline

- Research focus: LArTPC data reconstruction
- Demonstration of techniques
- Software tools
- Organization: where we are, where we are going

Big Picture Goal

My interest: LArTPC data reconstruction using Deep Neural Network (DNN)

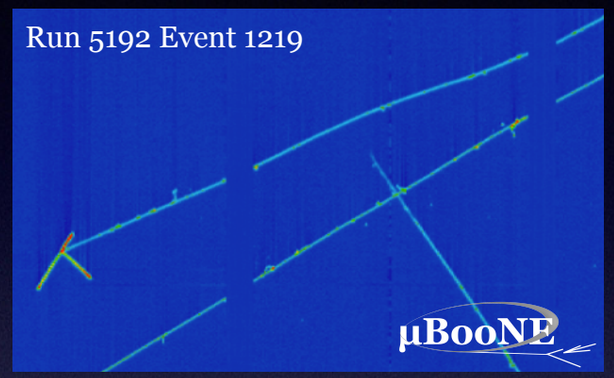
- **Use DNN as a feature extractor**
  - Instead of DNN telling me "CCQE event", I want it to tell me "1e1p topology", "vertex @ (x,y,z)", "two clusters of charge deposition" for "1e" and "1p"

- **DNN-based data reconstruction chain**
  - Develop a network for an individual reconstruction task first
  - Can combine networks later + end-to-end train
  - Or take individual network(s) and combine with traditional, hand-written algorithm based reco

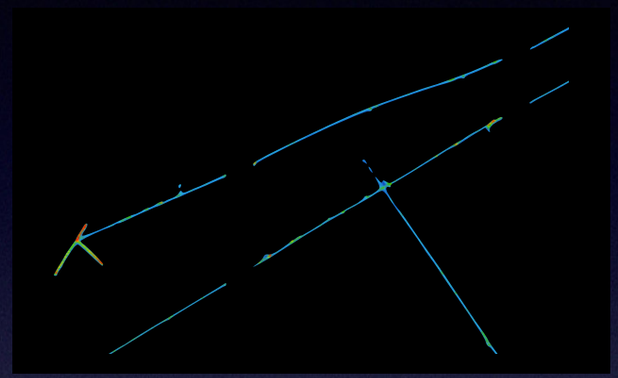
Big Picture Goal

Example: LArTPC Data Reconstruction Chain

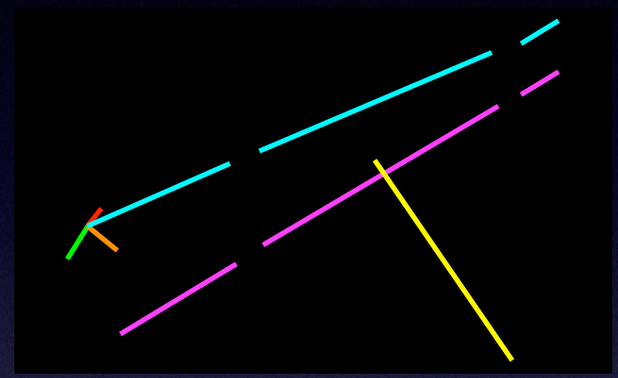
Aleena R. @ KSU
(DPF Proceeding)



2D Waveform



2D Hit Finding



Vertex/Clustering

possibly
iterative approach

3D Topological Reco

Big Picture Goal

Example: LArTPC Data Reconstruction Chain

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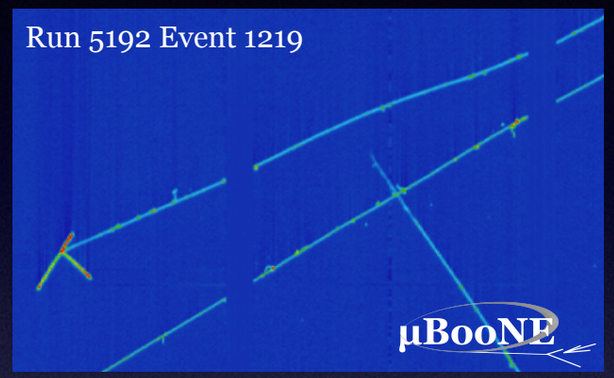
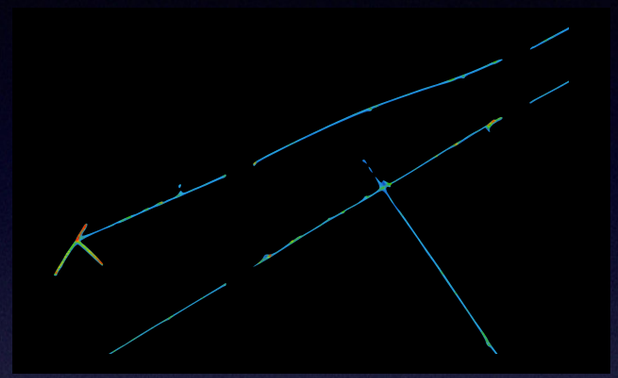
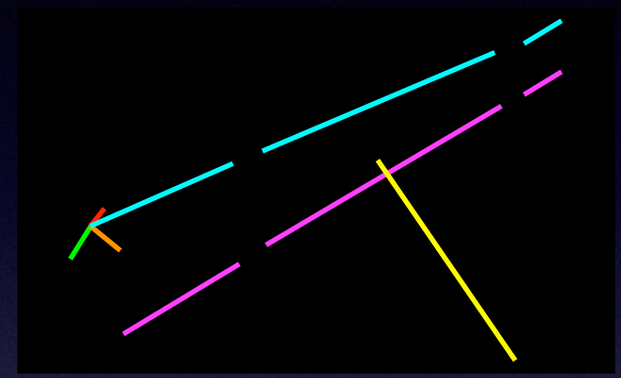


2D Waveform



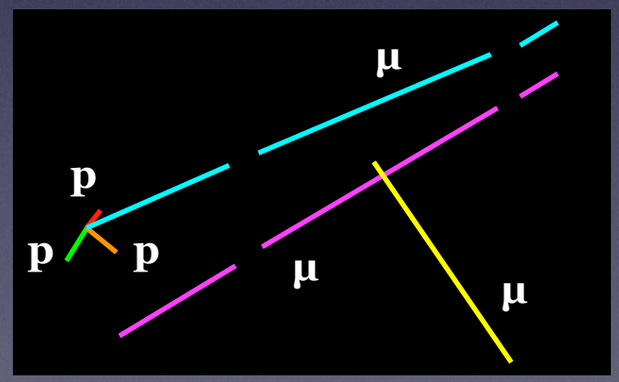
2D Hit Finding



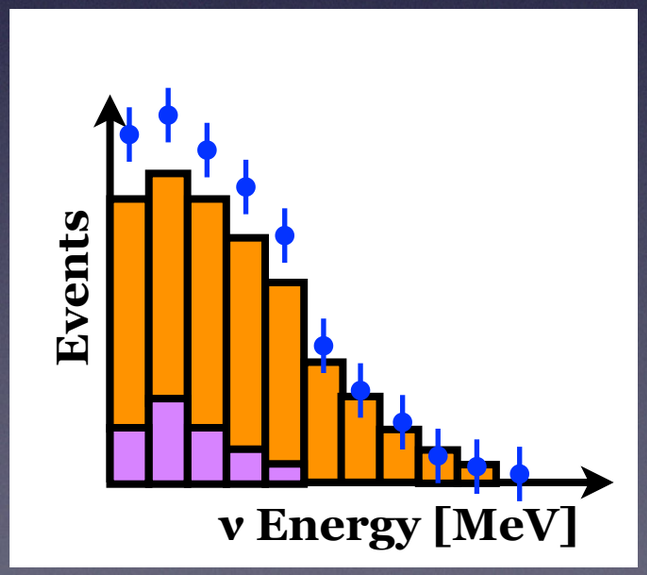
Vertex/Clustering

possibly
iterative approach

3D Topological Reco



Particle ID
(Interaction Classifier)



Energy Reco

Big Picture Goal

Example: LArTPC Data Reconstruction Chain

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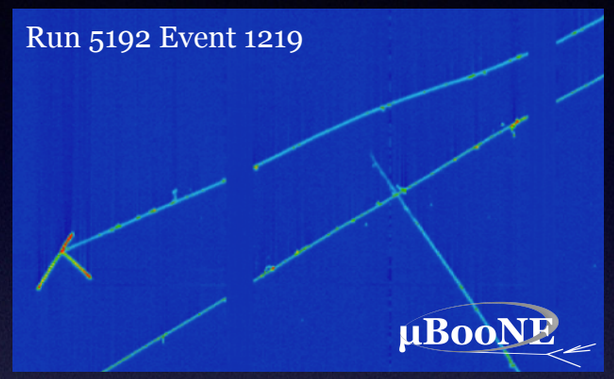
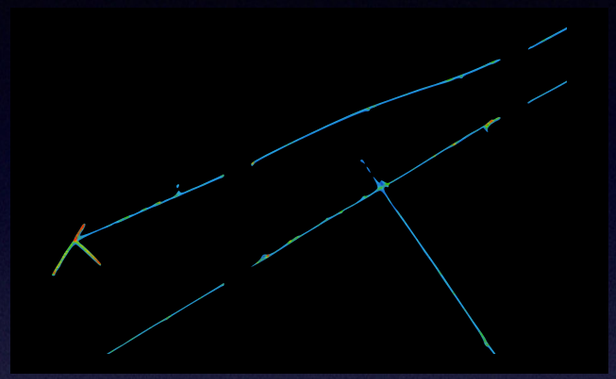
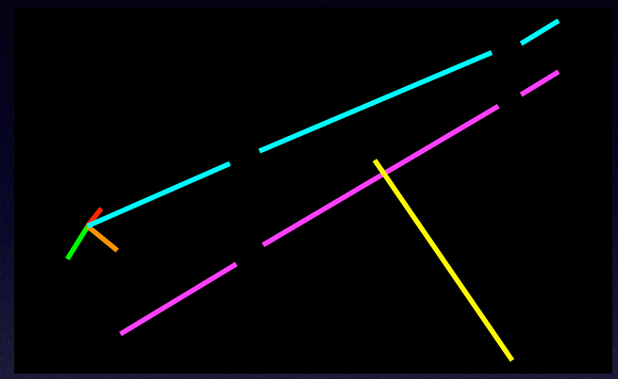
(DPF Proceeding)







2D Waveform

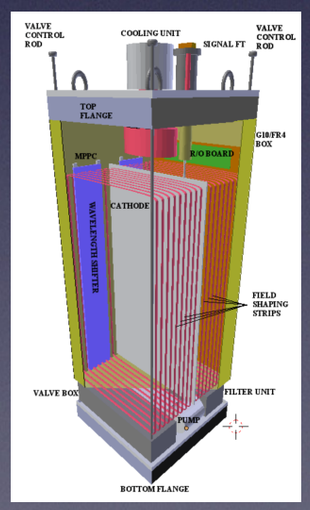
2D Hit Finding

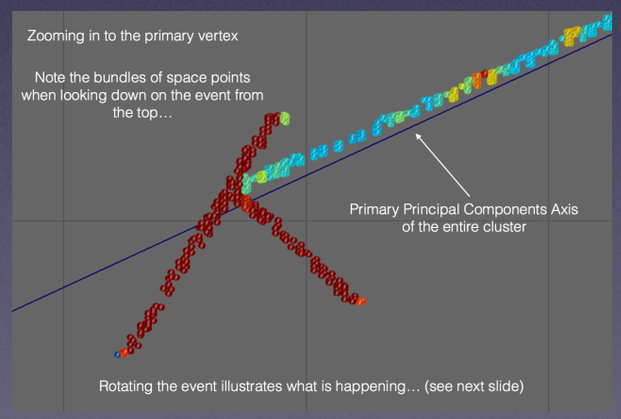
Vertex/Clustering

WireCell

Cluster3D @ LArSoft

possibly iterative approach

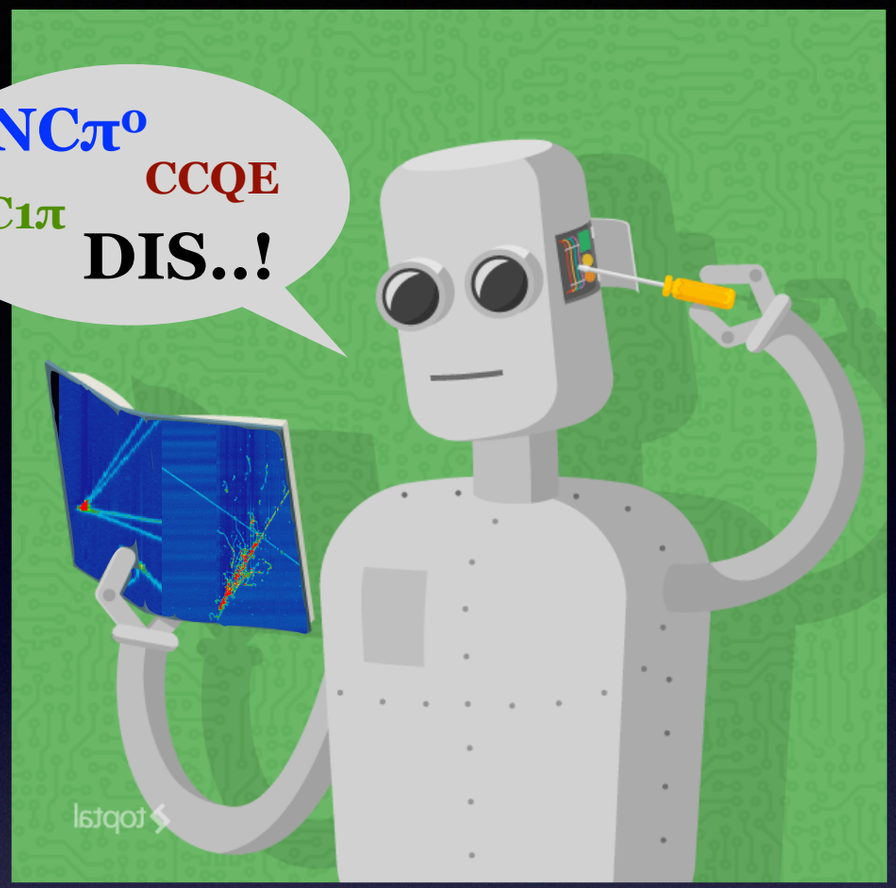


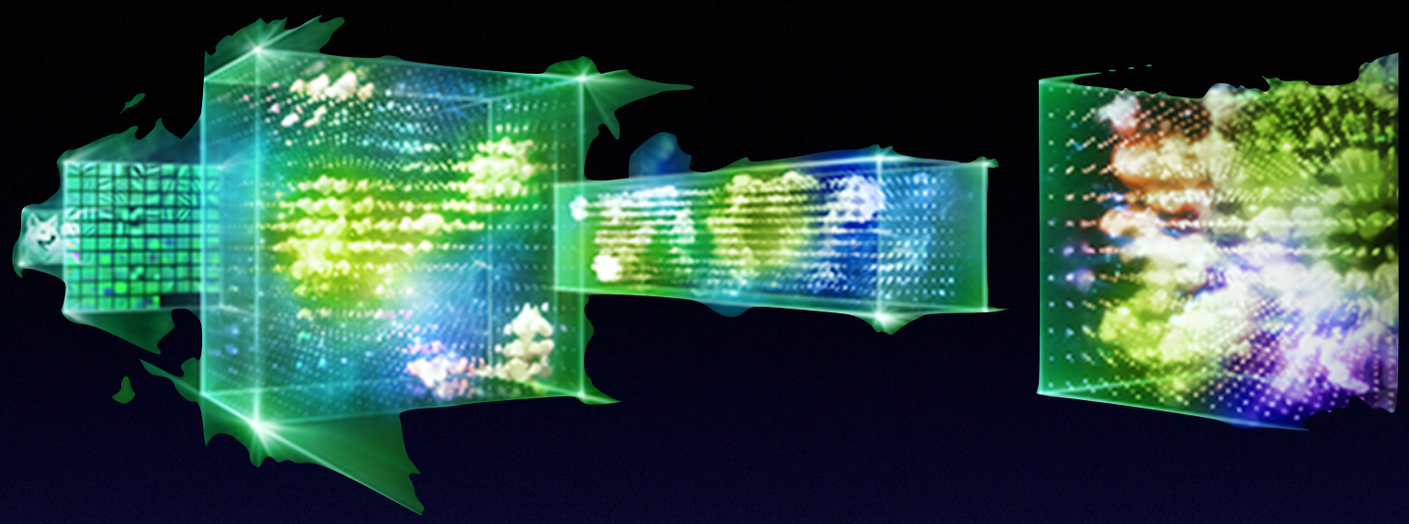


Pixel Readout LArTPC

3D Hit/Point Finding

3D Topological Reco





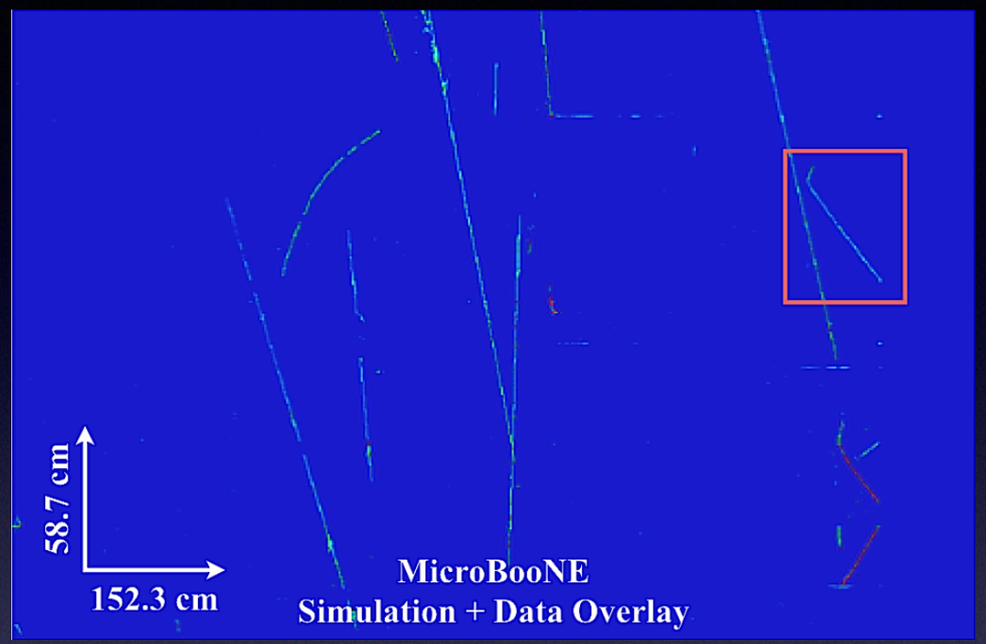
Deep Neural Network Technique Demos

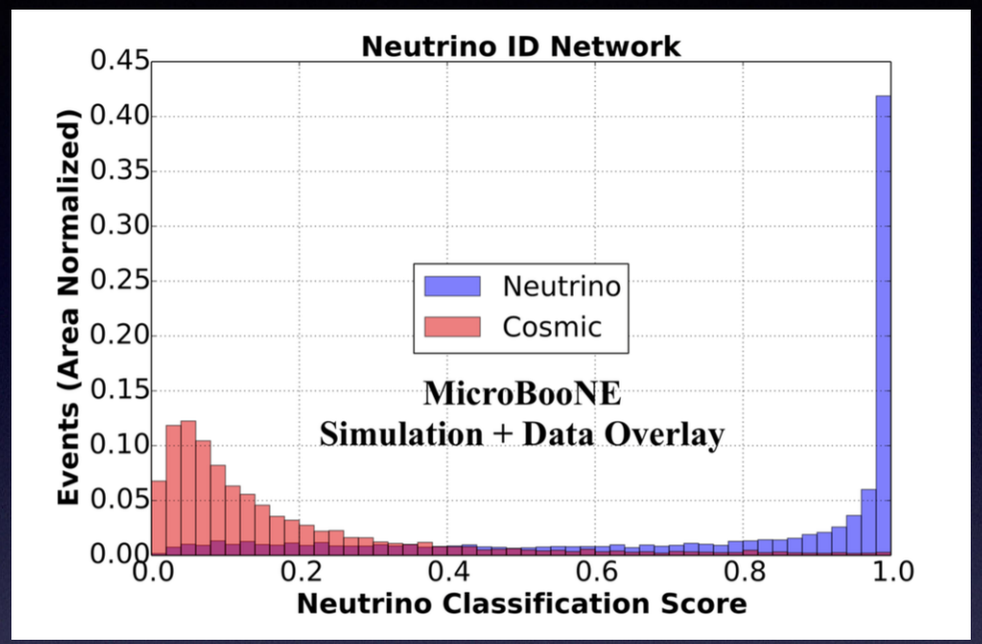
Outline

- Research focus: LArTPC data reconstruction
- **Demonstration of techniques**
- Software tools
- Organization: where we are, where we are going

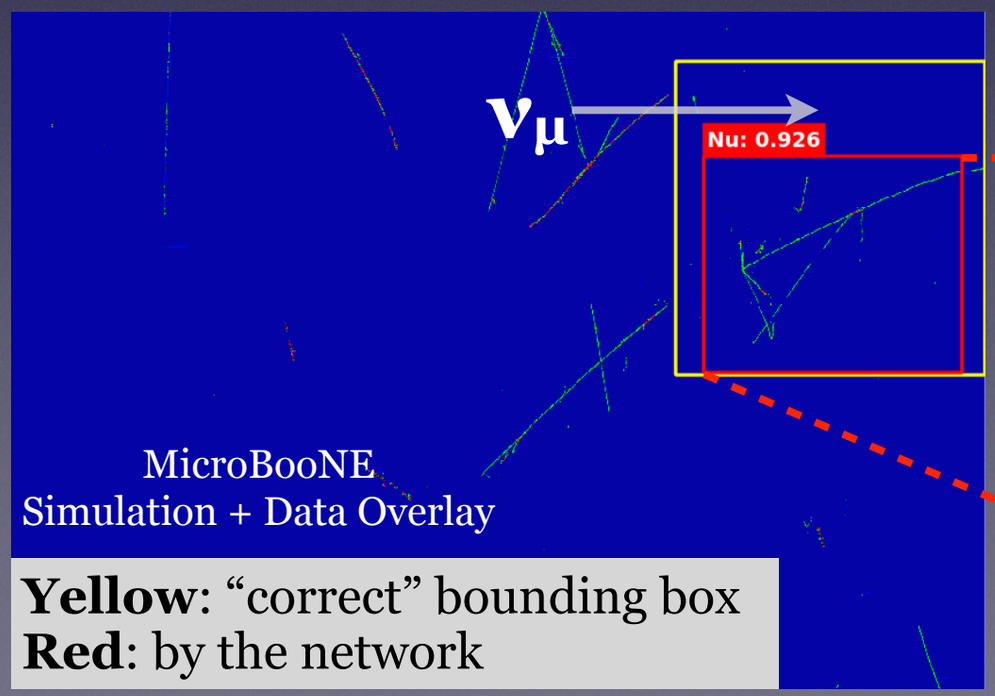
Technique Demonstrations in LArTPC

2D Image Classification … JINST 12, P03011 (2017)

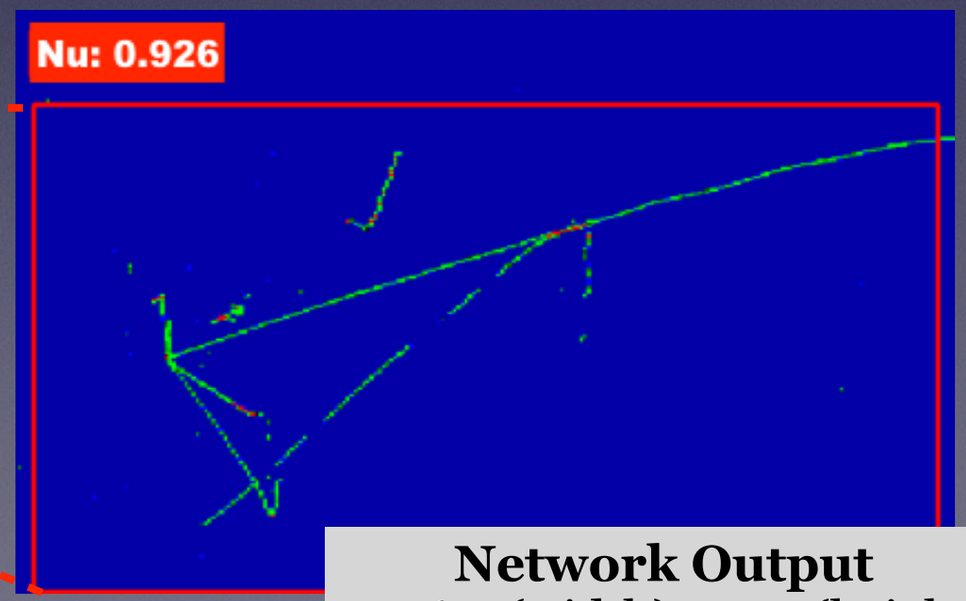




2D Object Detection … JINST 12, P03011 (2017)



Yellow: "correct" bounding box
Red: by the network

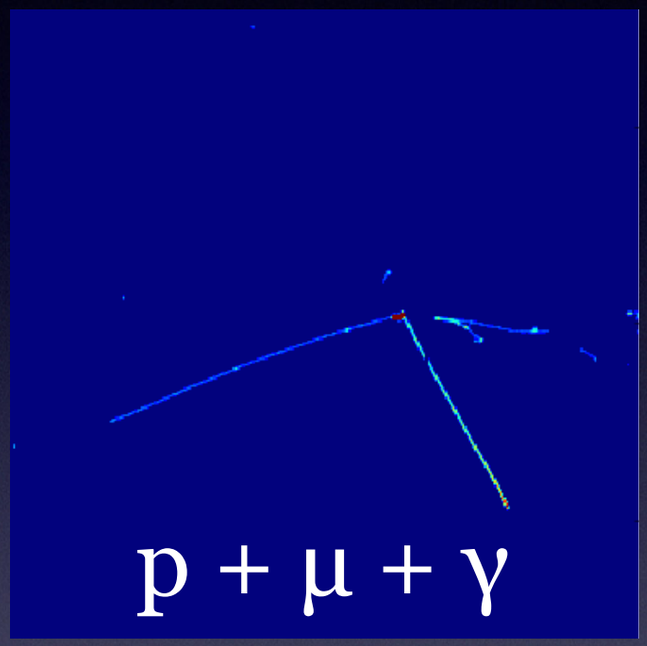


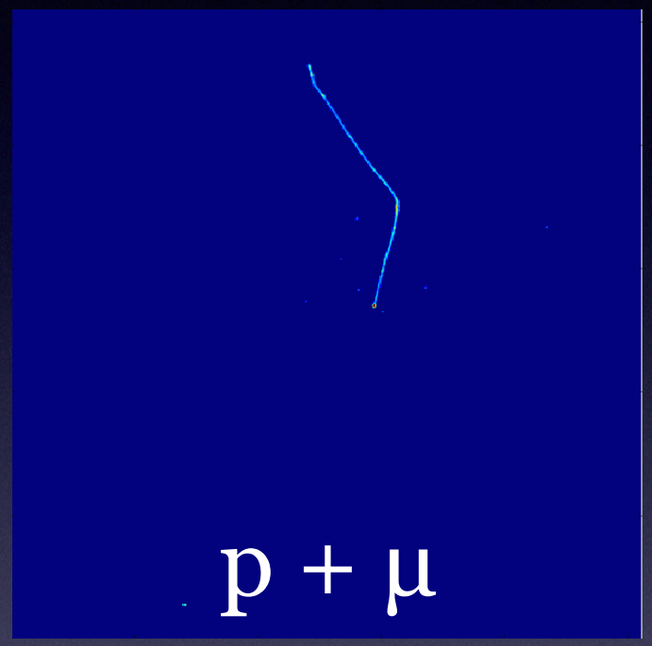
Network Output
≃ 2.6m (width) x 1 m (height)

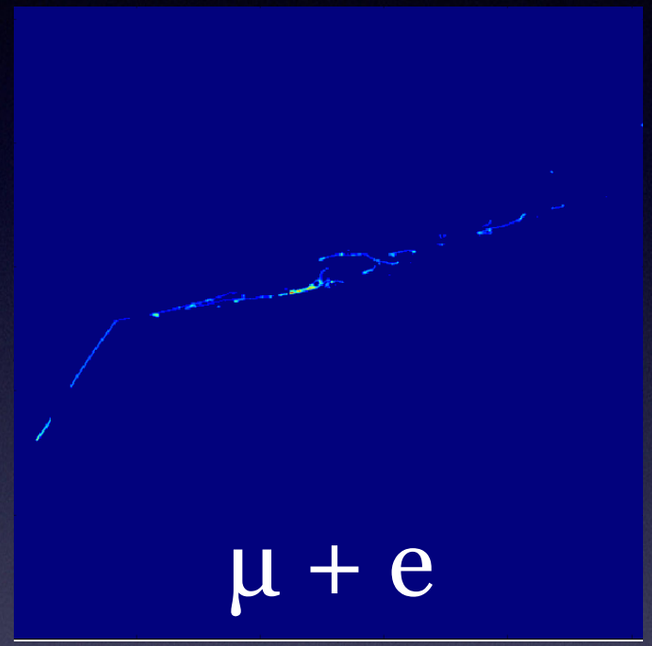
Technique Demonstrations in LArTPC

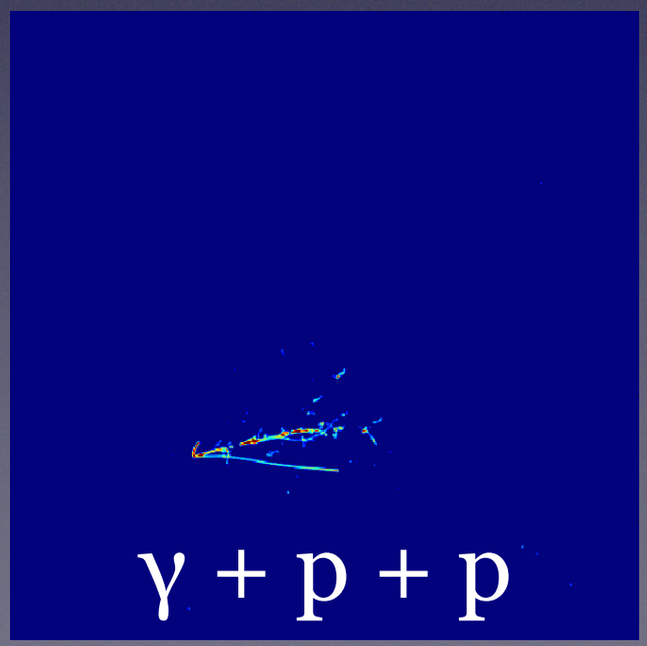
Multi-Particle ID as final state classifier

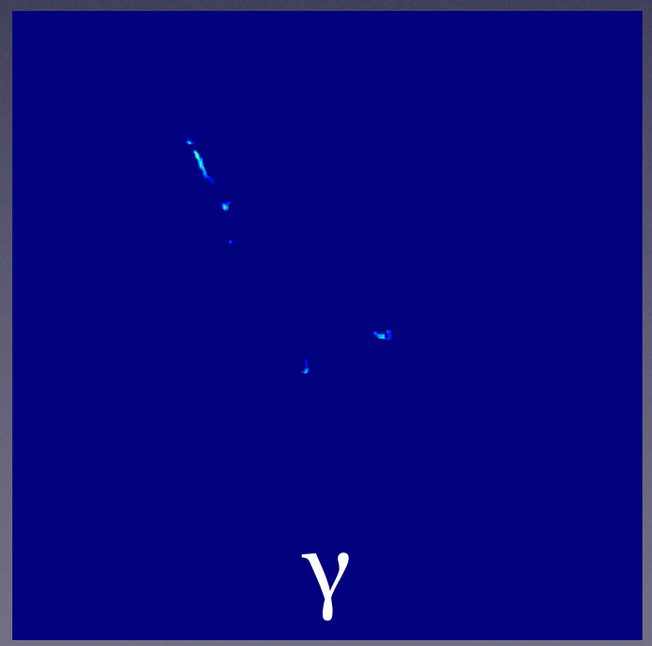
- Predicts particle type & multiplicity (in progress)

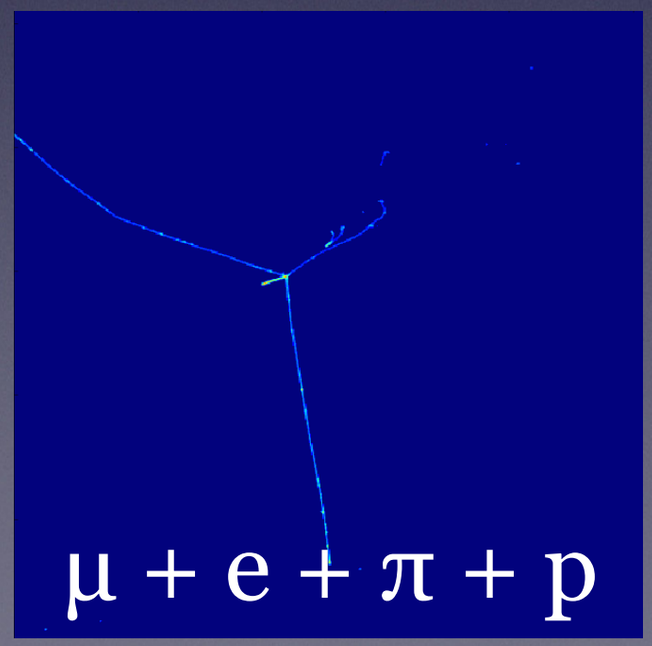






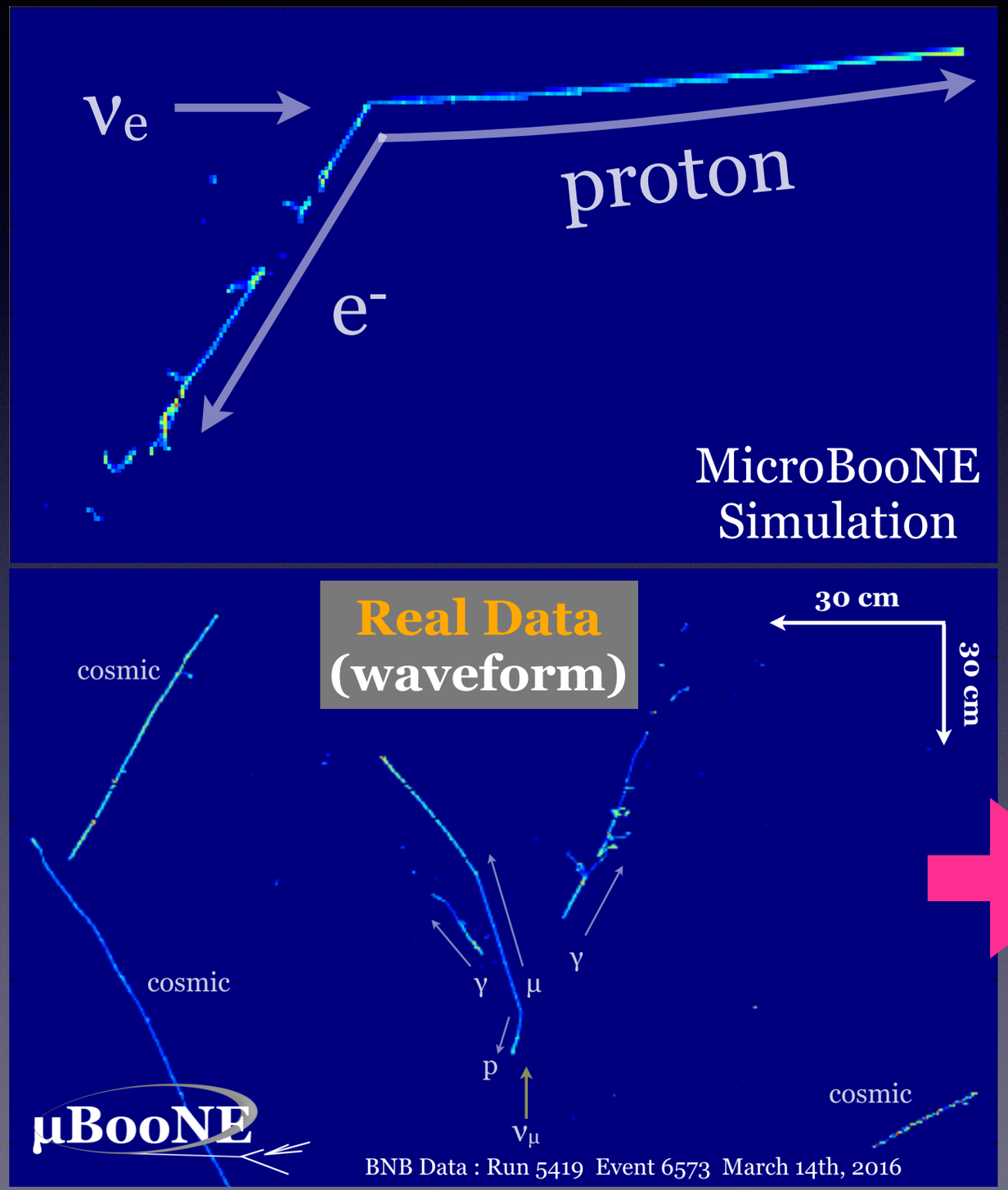


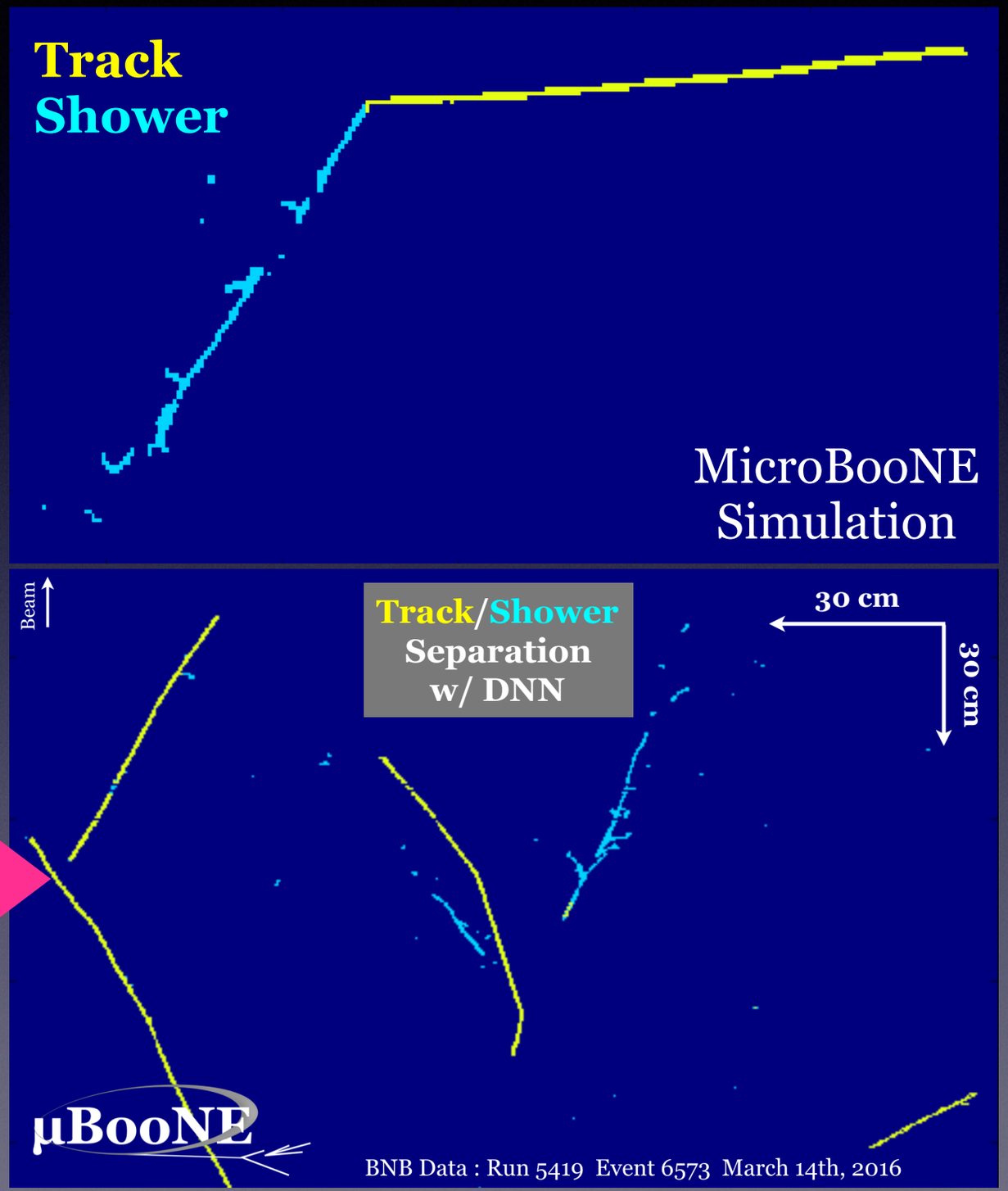




Technique Demonstrations in LArTPC

2D Semantic Segmentation



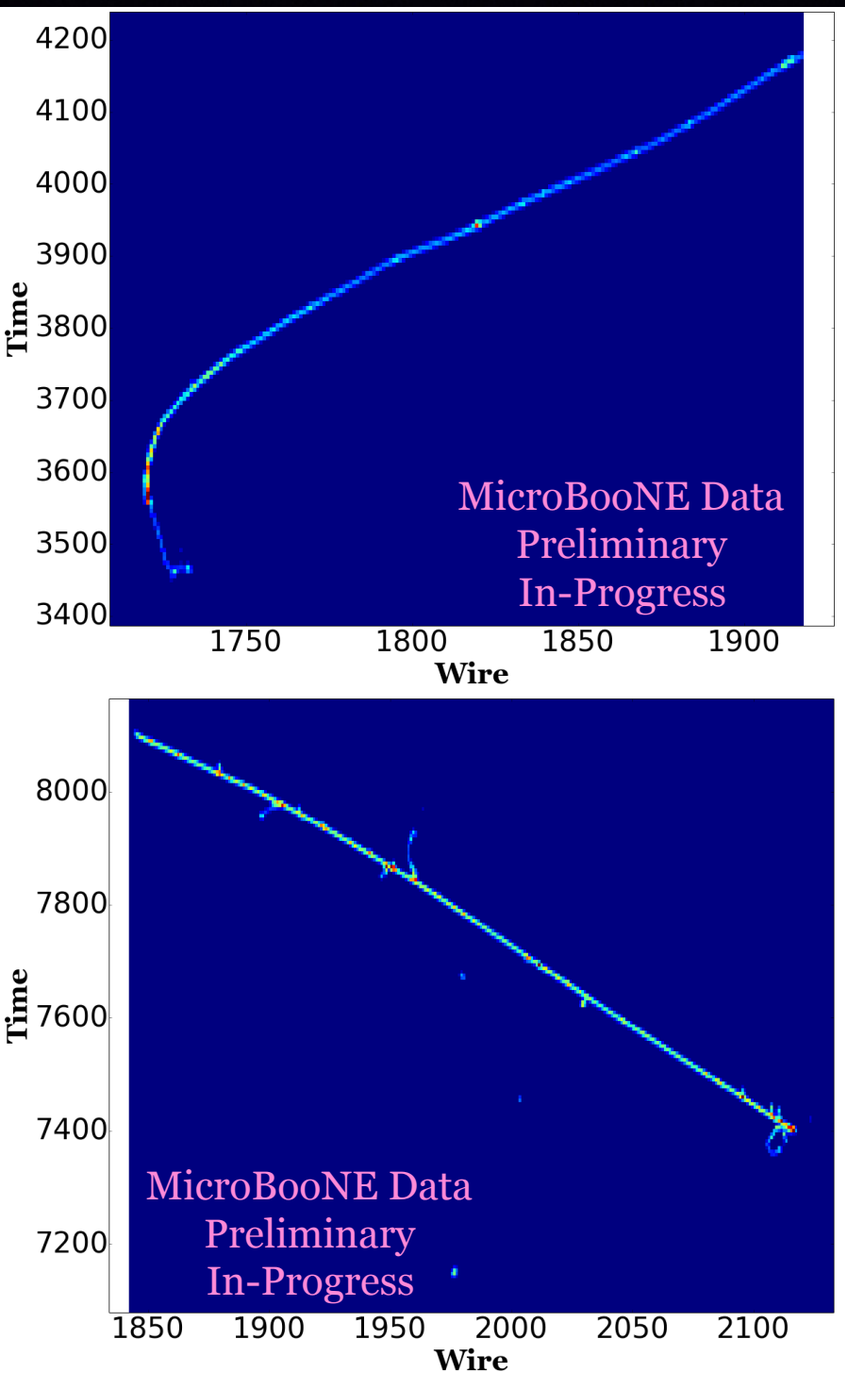


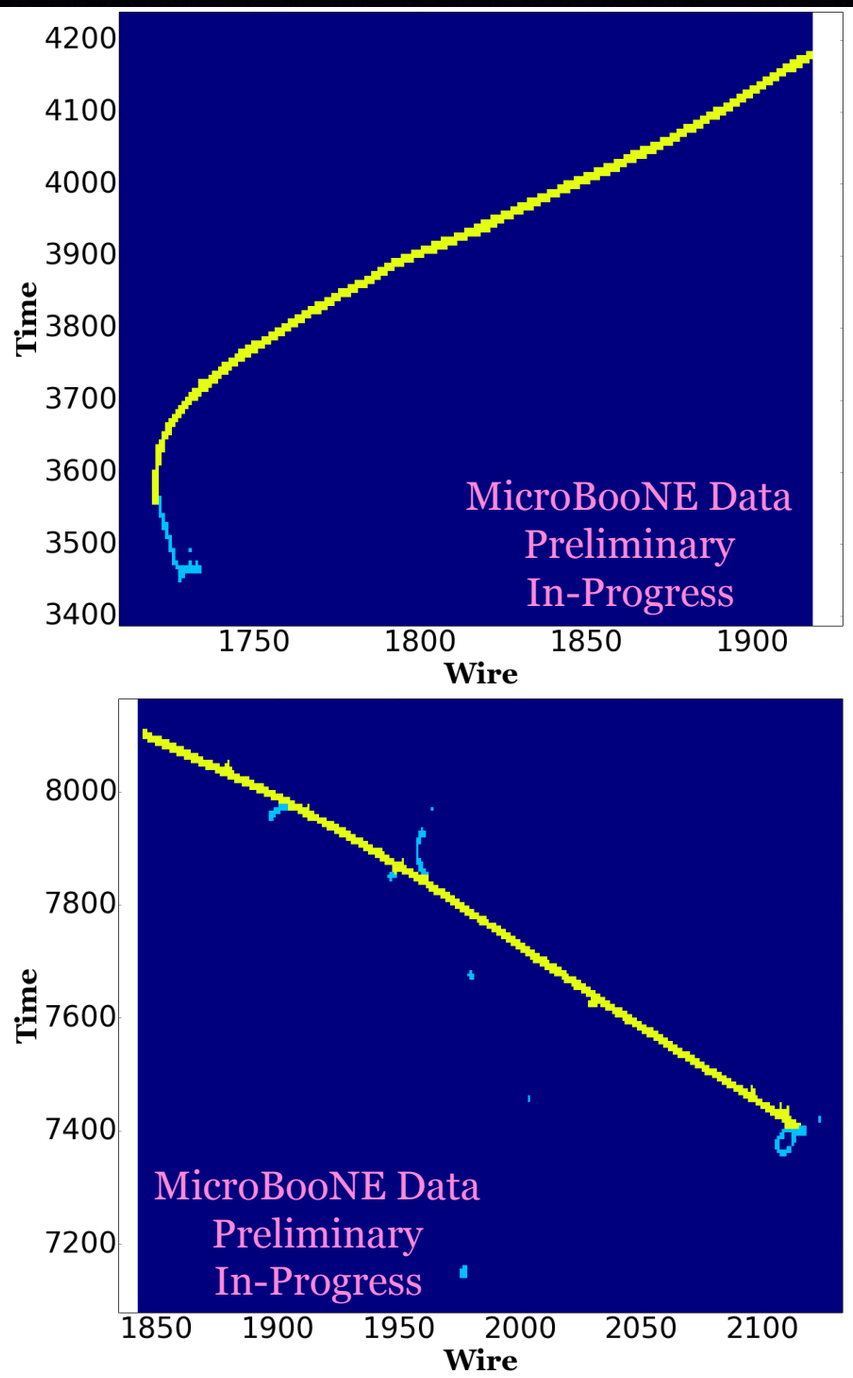
DATA CCπ^0 Candidate

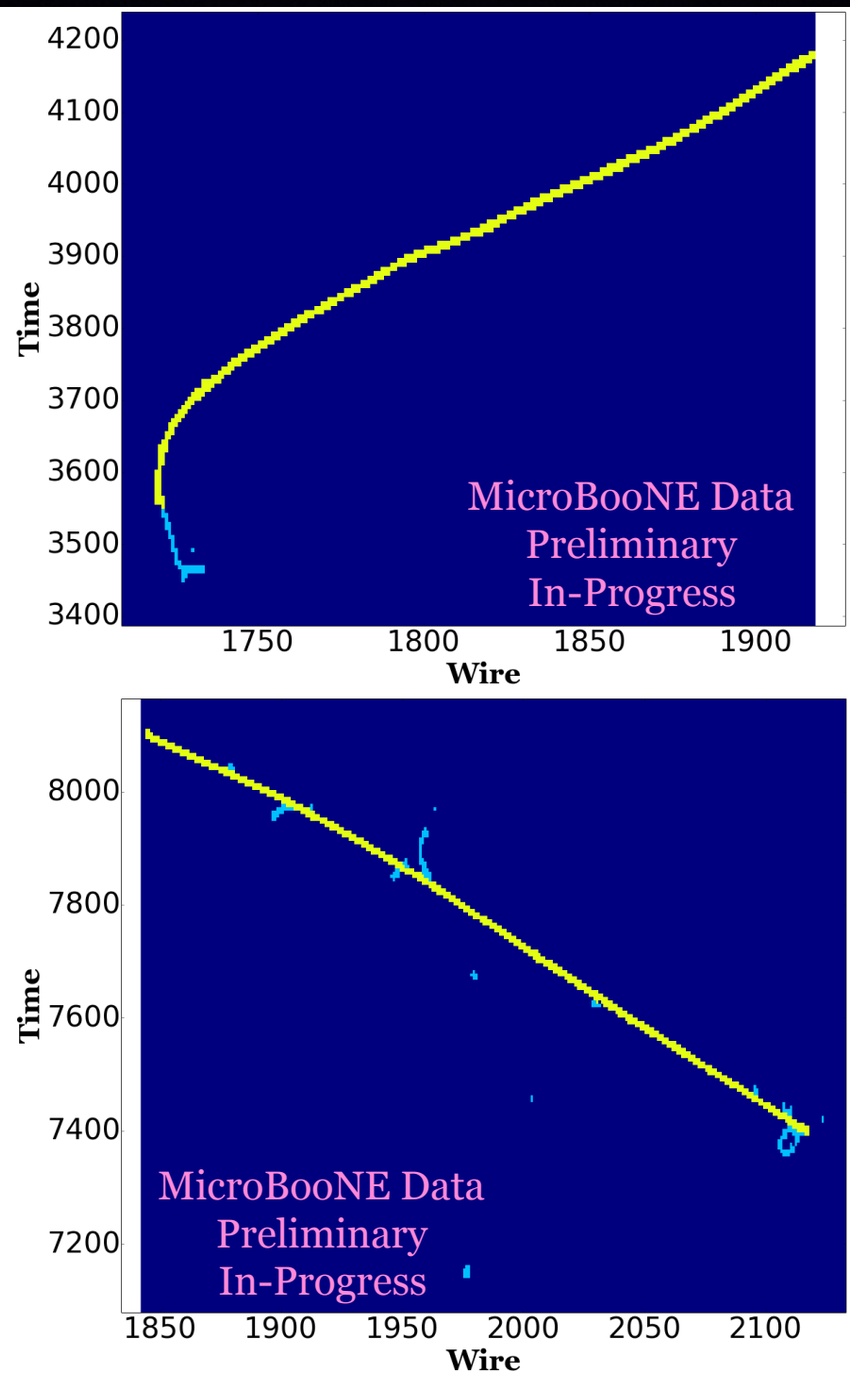
Pixel-level analysis via custom CNN

Technique Demonstrations in LArTPC

Quantitative Validation w/ Real Data



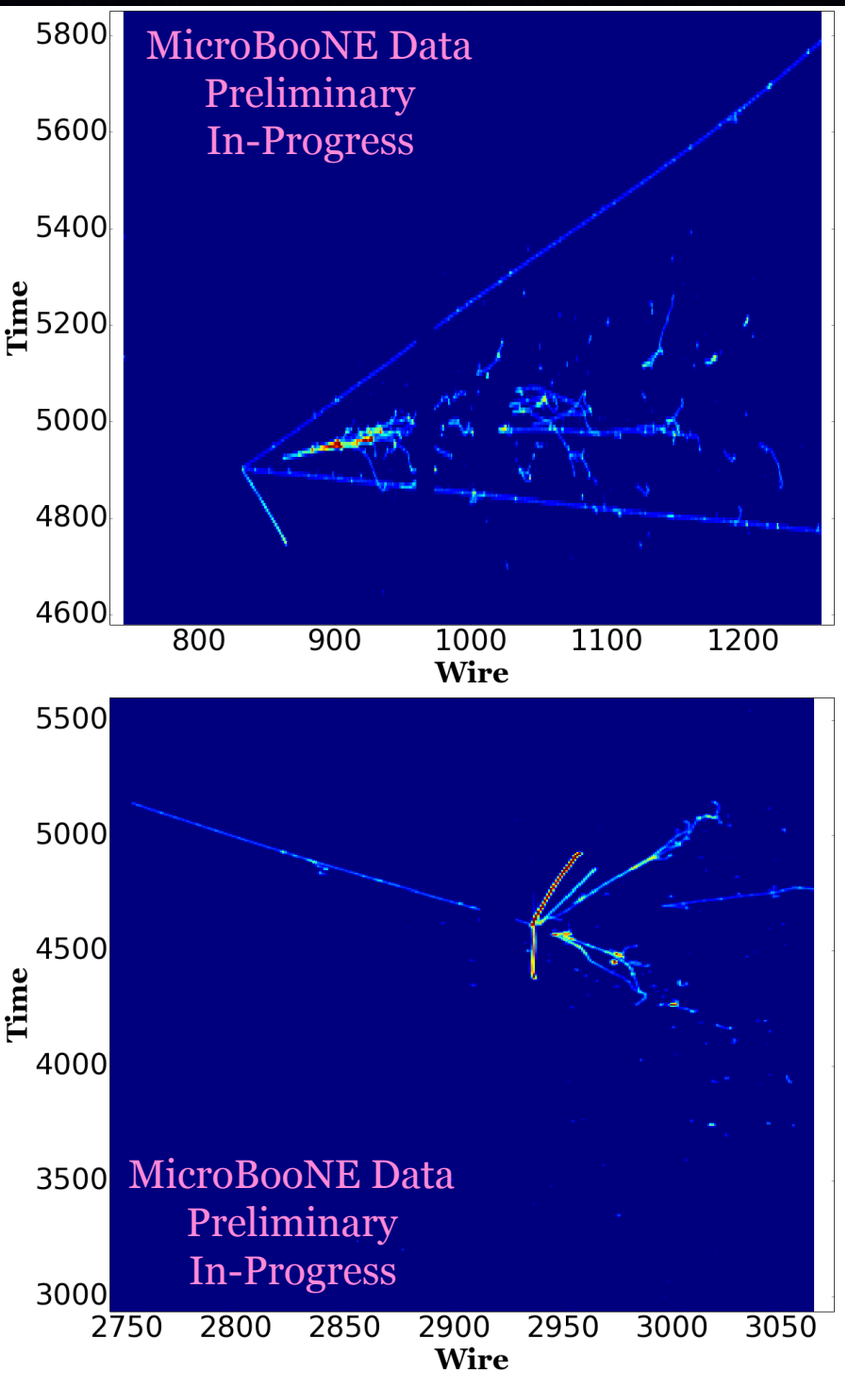


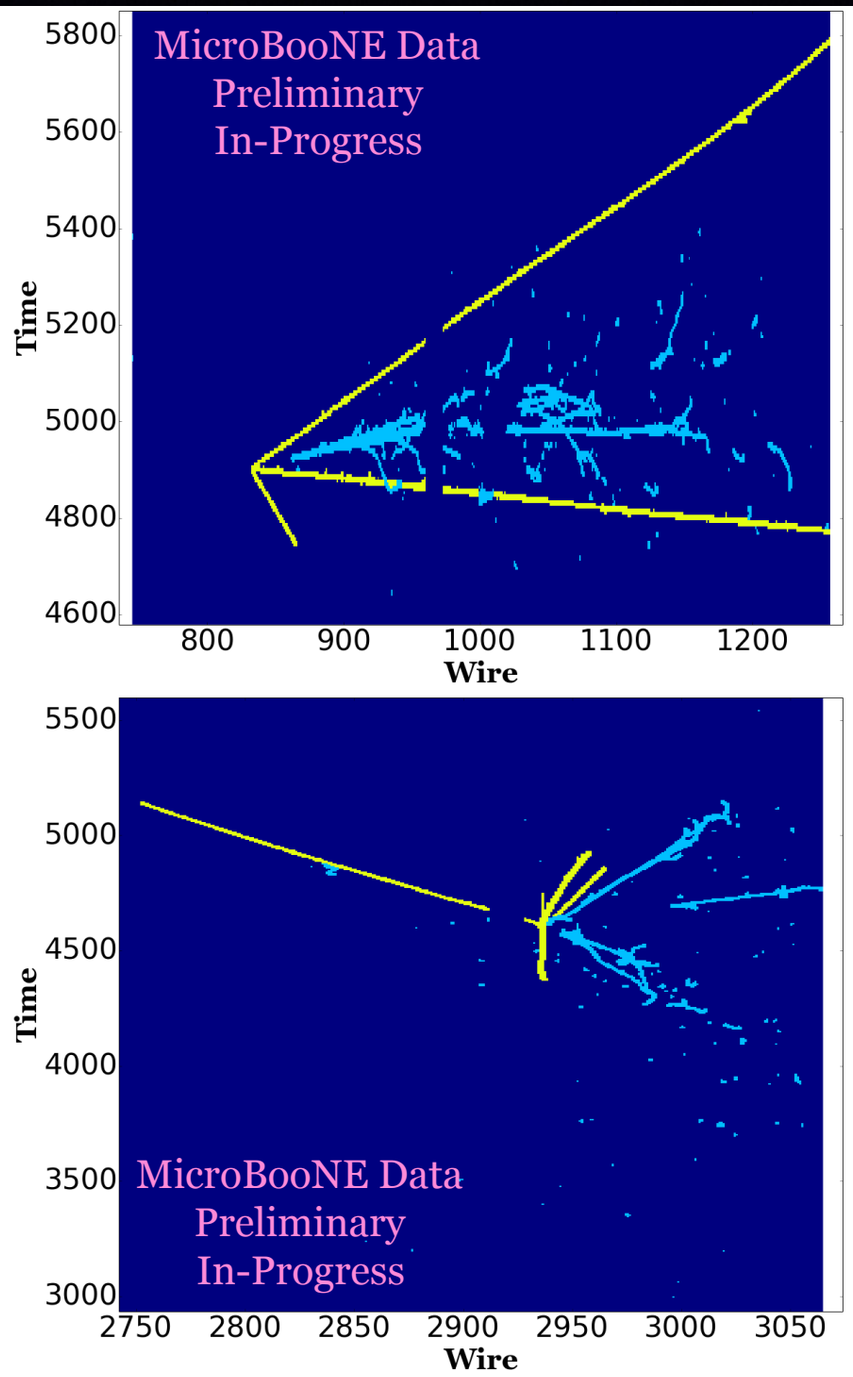


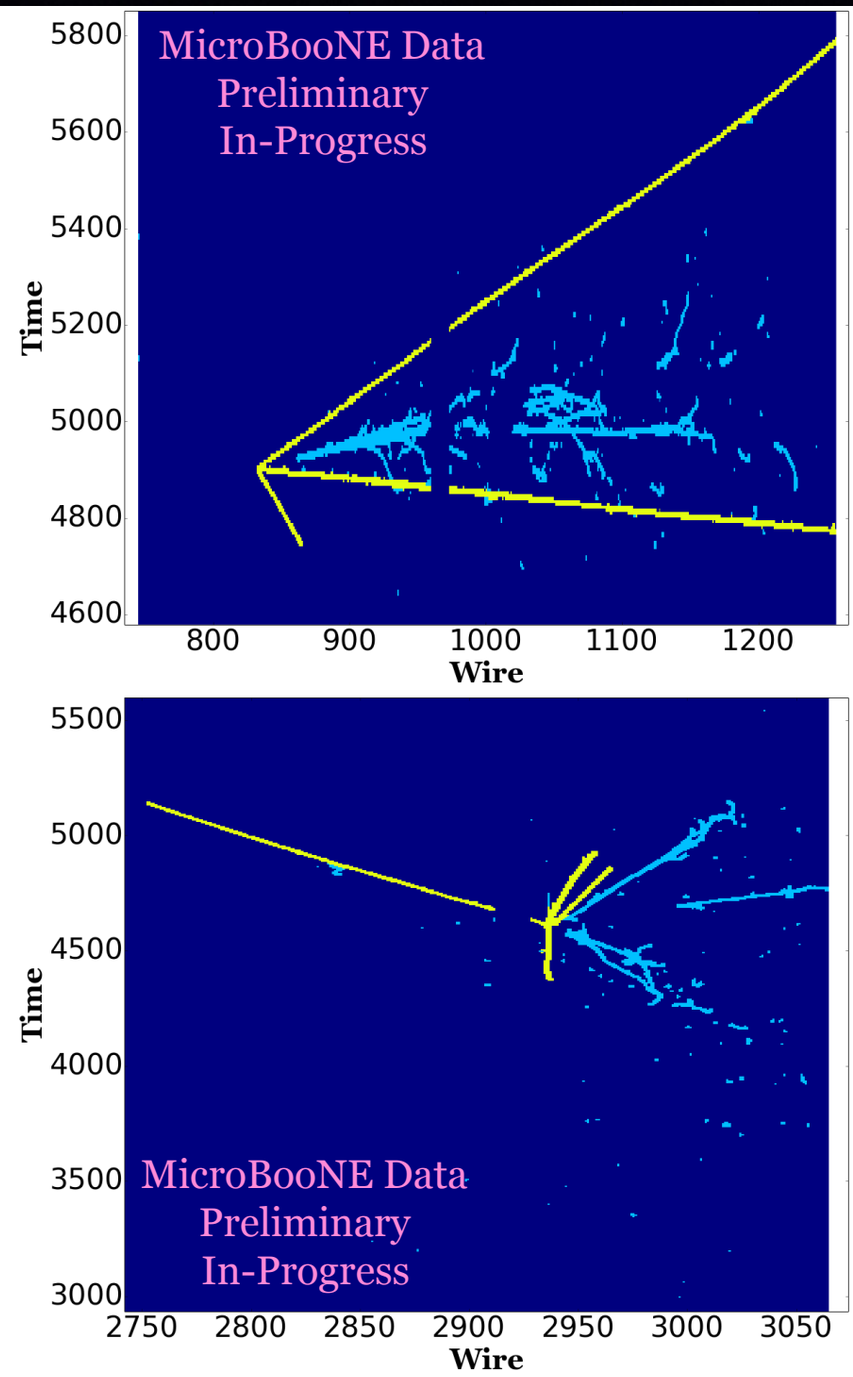
Input Image | Human Label | SSNet Label

Technique Demonstrations in LArTPC

Quantitative Validation w/ Real Data



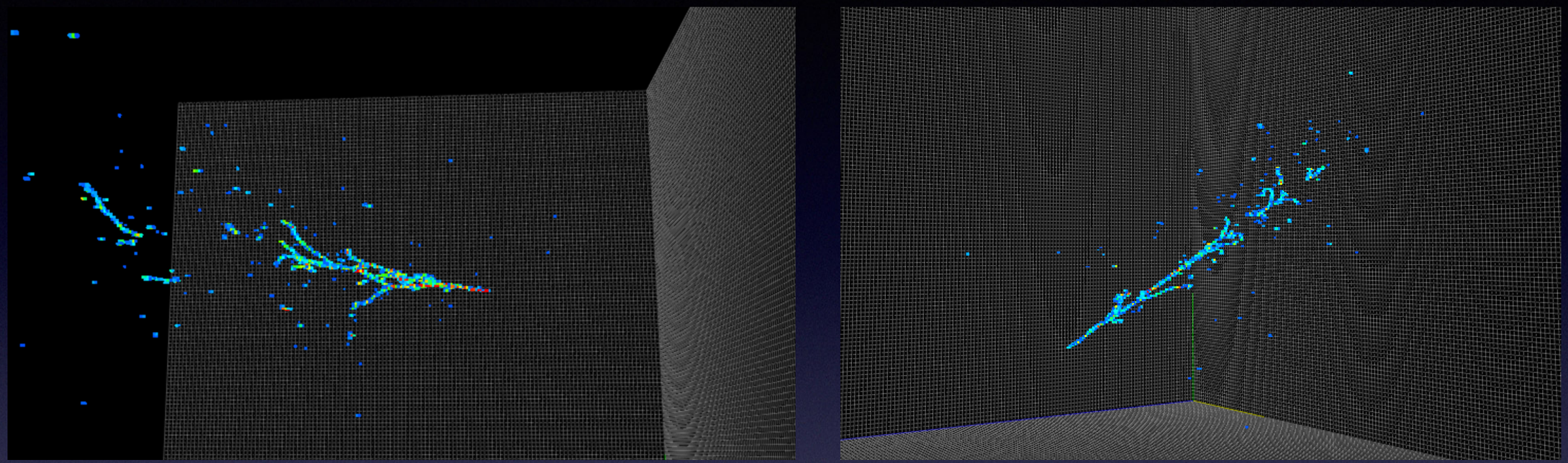




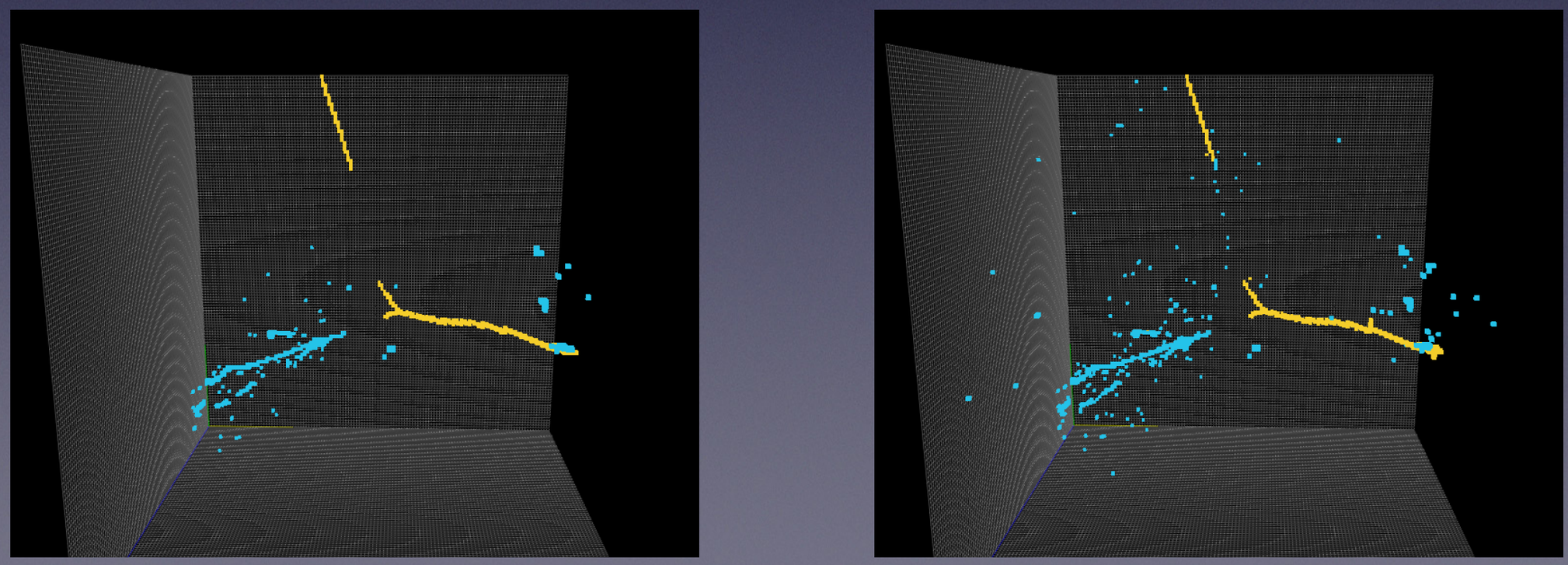
Input Image | Human Label | SSNet Label

Technique Demonstrations in LArTPC

3D “Image Classification” … demo-ed in UB/SBND

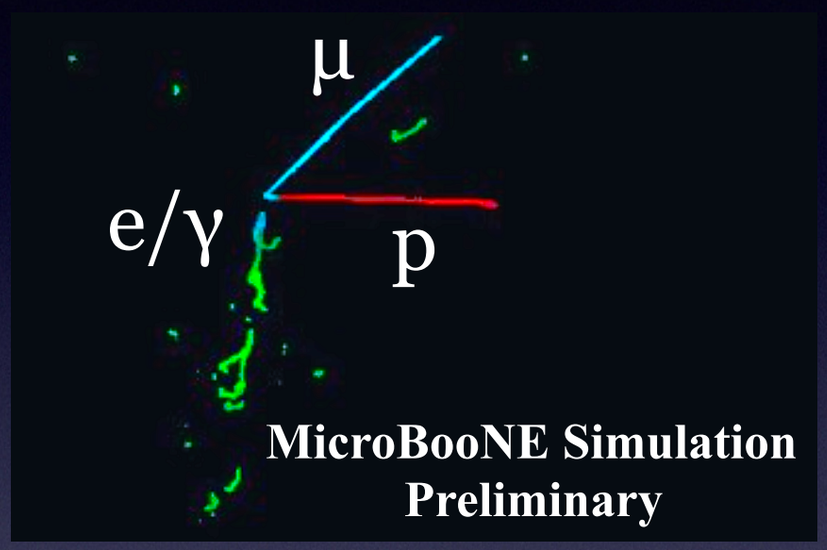


3D Semantic Segmentation … (demo-ed in **open MC**)



Technique Demonstrations in LArTPC

2D/3D Vertex Finder + Particle Clustering (via Instance-Aware Semantic Segmentation)

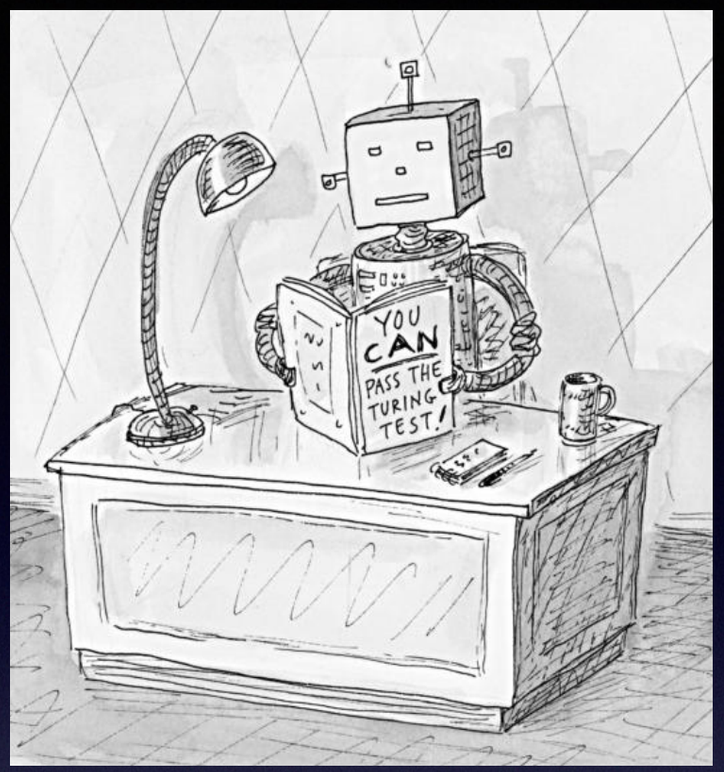


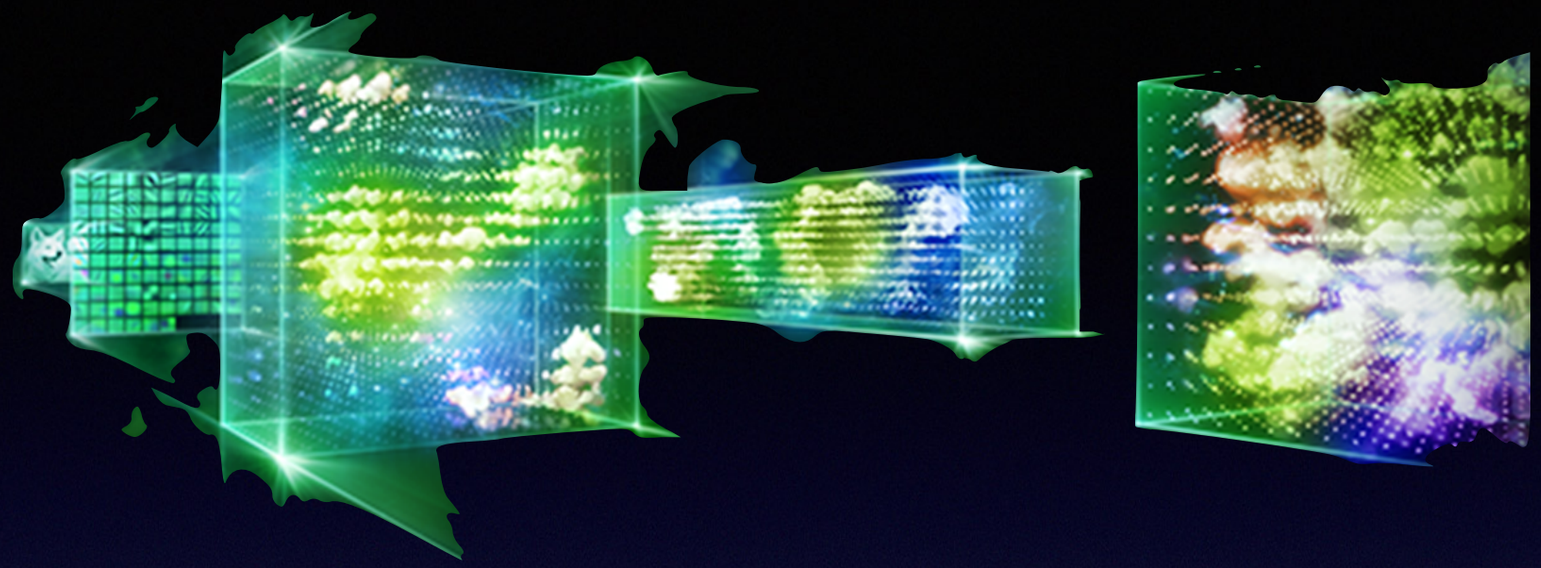
Shower/MIP/HIP Semantic Segmentation

Instance-aware Semantic Segmentation (MNC, 2015)
R-CNN based technique using region proposal

Work-in-Progress

- Mask R-CNN as the latest model in this family
- 2D/3D Faster R-CNN in TF for LArTPC, then implement Mask R-CNN (on-going)





Software Tools for DNN Development

Outline

- Research focus: LArTPC data reconstruction
- Demonstration of techniques
- **Software tools**
- Organization: where we are, where we are going

Our Software Tools

DeepLearnPhysics

Deep Neural Network Tools for Physics Analysis

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larcv-tutorial

Tutorial of LArCV data products and interface with tensorflow.

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Python C++
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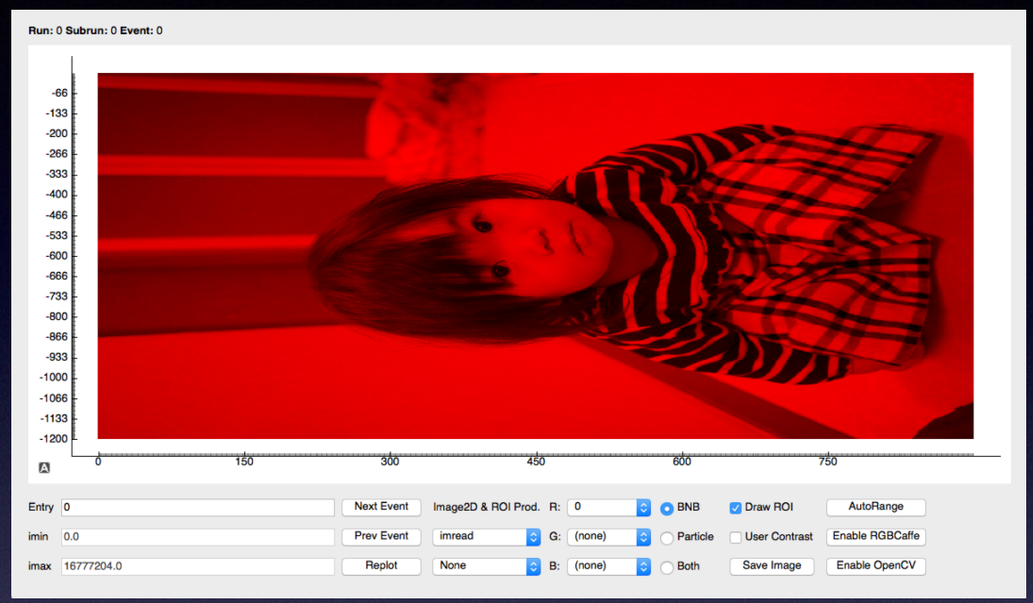
"main" software

- 2D/3D data representation + file I/O
- (threaded) event processors
- image/volumetric data processing algorithms
- Numpy/OpenCV/DNN software interfaces
- Original: github.com/LArbys/LArCV (still *very* active development but UB analysis specific)

LArCV: Extensive Python Interface

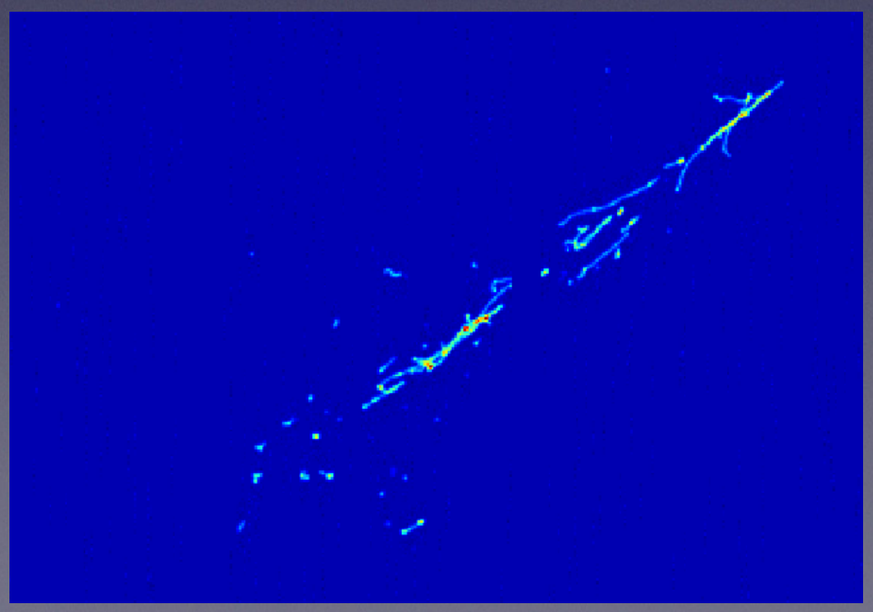
```
from larcv import larcv
# read-in image file to create one Image2D instance
image2d = larcv.imread('sakura.jpg')
```



Visualization w/
LArCV RGB viewer

```
# Note here that std::vectors in pyroot are iterable
# larcv has a helper function to convert std::vector to numpy array, so we can use that:
_image_array = larcv.as_ndarray(image)
```

```
#Show the image with imshow:
fig = plt.figure(figsize=(16,16))
plt.imshow(_image_array.T, interpolation='none')
```



More examples covered
in Jupyter notebooks for tutorial
github.com/DeepLearnPhysics/larcv-tutorial

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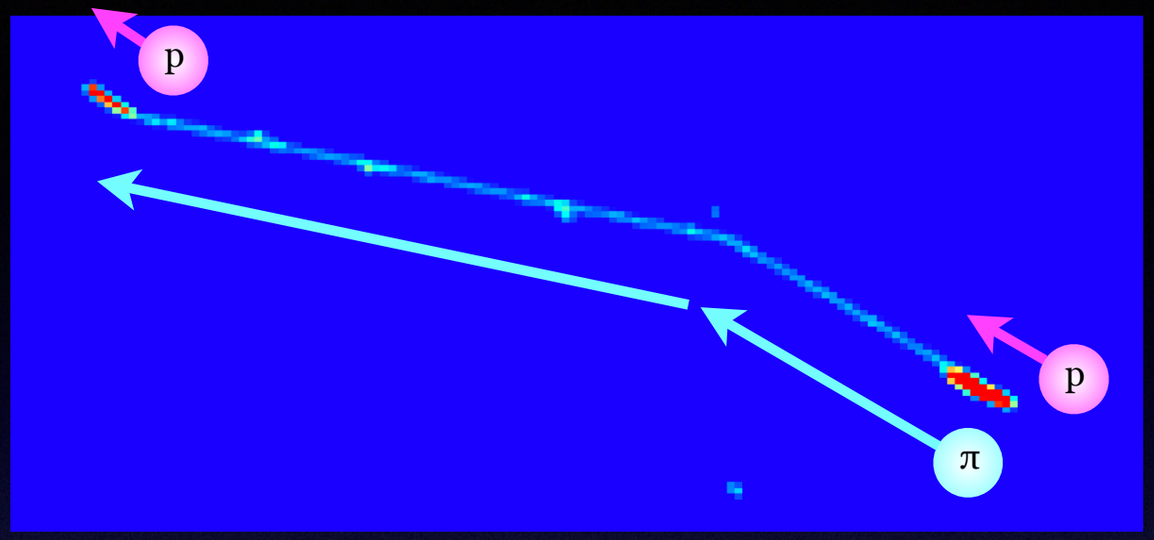
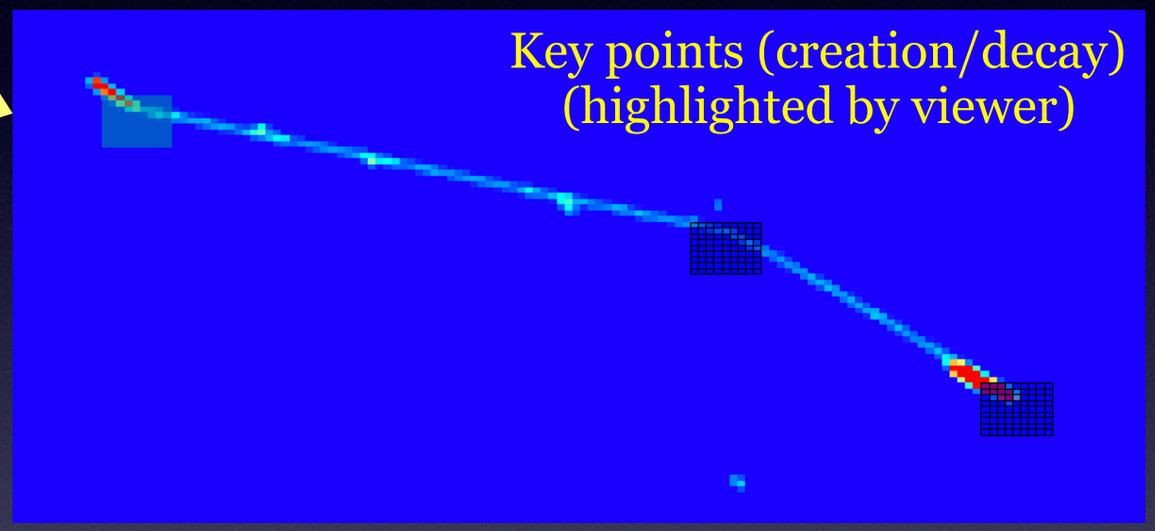
2D/3D Data Visualization Tool

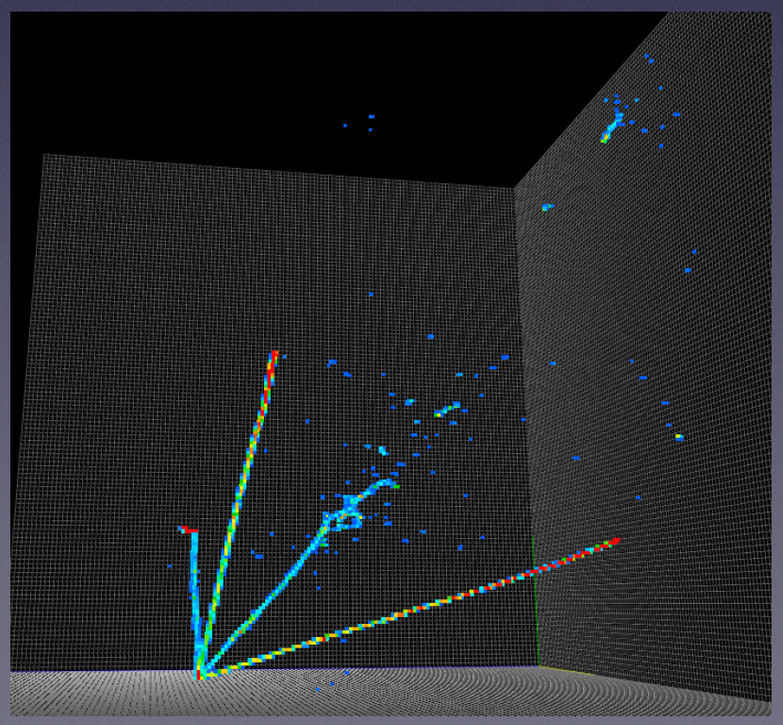
- LArCV specific tool
- Visualize pixels/voxels, clusters, correlation across images, etc.
- Crucial :)

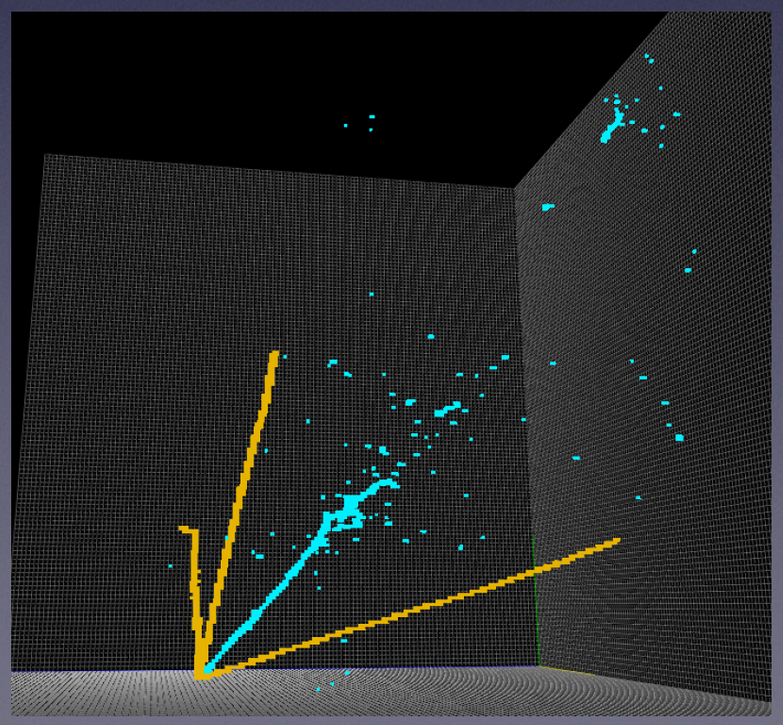
Visualization Tools

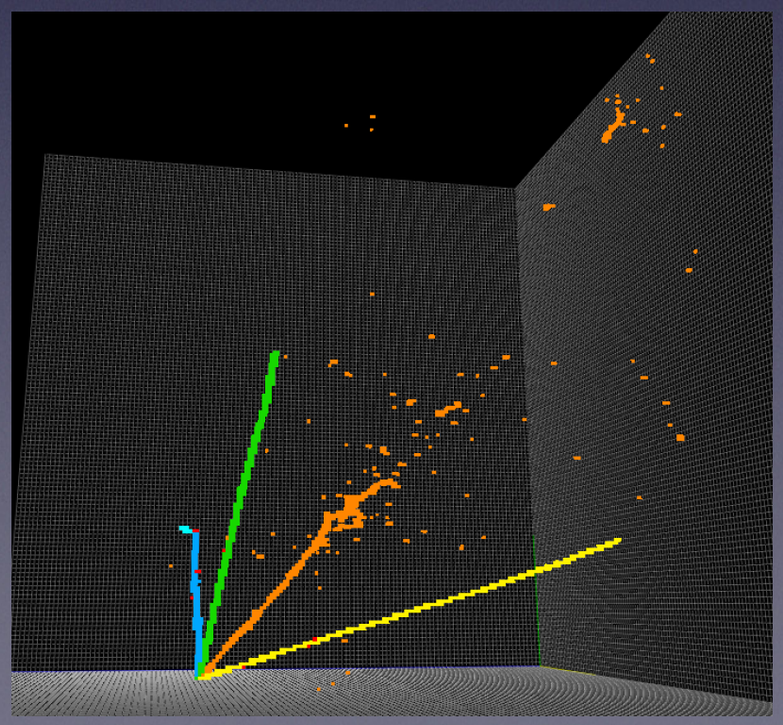




2D & 3D with an interpretation of clusters (demo on youtube for 2D and 3D)







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LArSoft => LArCV Translation Tool

- Experiment-specific interface functions needed
- Algorithms to construct 2D/3D data, “truth info” (particle level, pixel/voxel level) creation
- Can create info w/ or w/o detector sim
- Can use raw waveform, de-conv. waveform, reconstructed 2D hit and 3D space point

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Tutorial Tools

- Introduction to Numpy/Jupyter/LArCV
- Network training practice w/ TensorFlow using "open" LArTPC data set (2D/3D classification & semantic segmentations)

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Deep Neural Network Tools for Physics Analysis

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Supera
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Tutorial of LArCV data products and
Jupyter Notebook ★ 1 Updated 1

faster-rcnn
Python ★ 1 Updated 18 days ago

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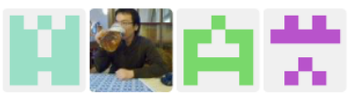
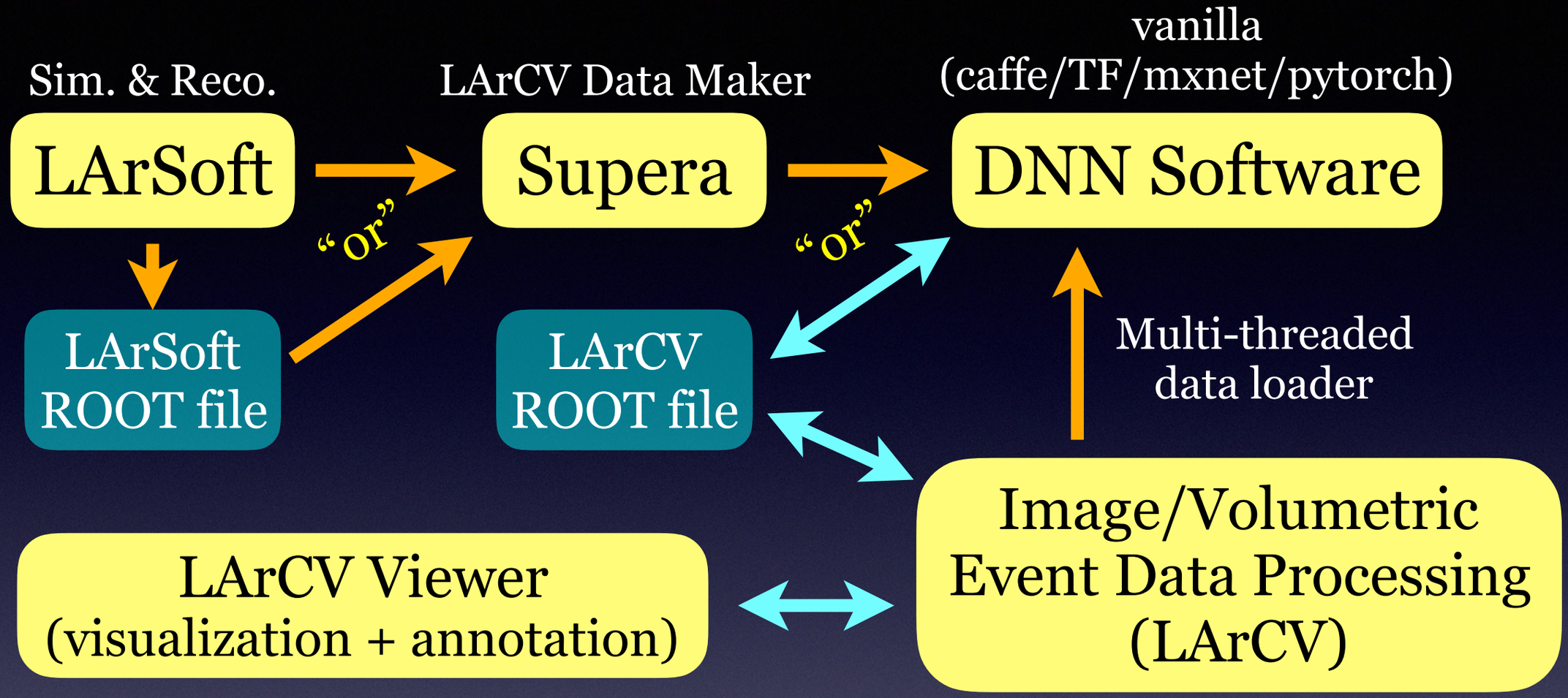


Invite someone

Network Developments

- U-ResNet for 2D/3D semantic segmentation (generic beyond track/shower)
- faster-rcnn implementation in TF, to be expanded to 3D, to be implemented with ROI warping and ROI align layer operations

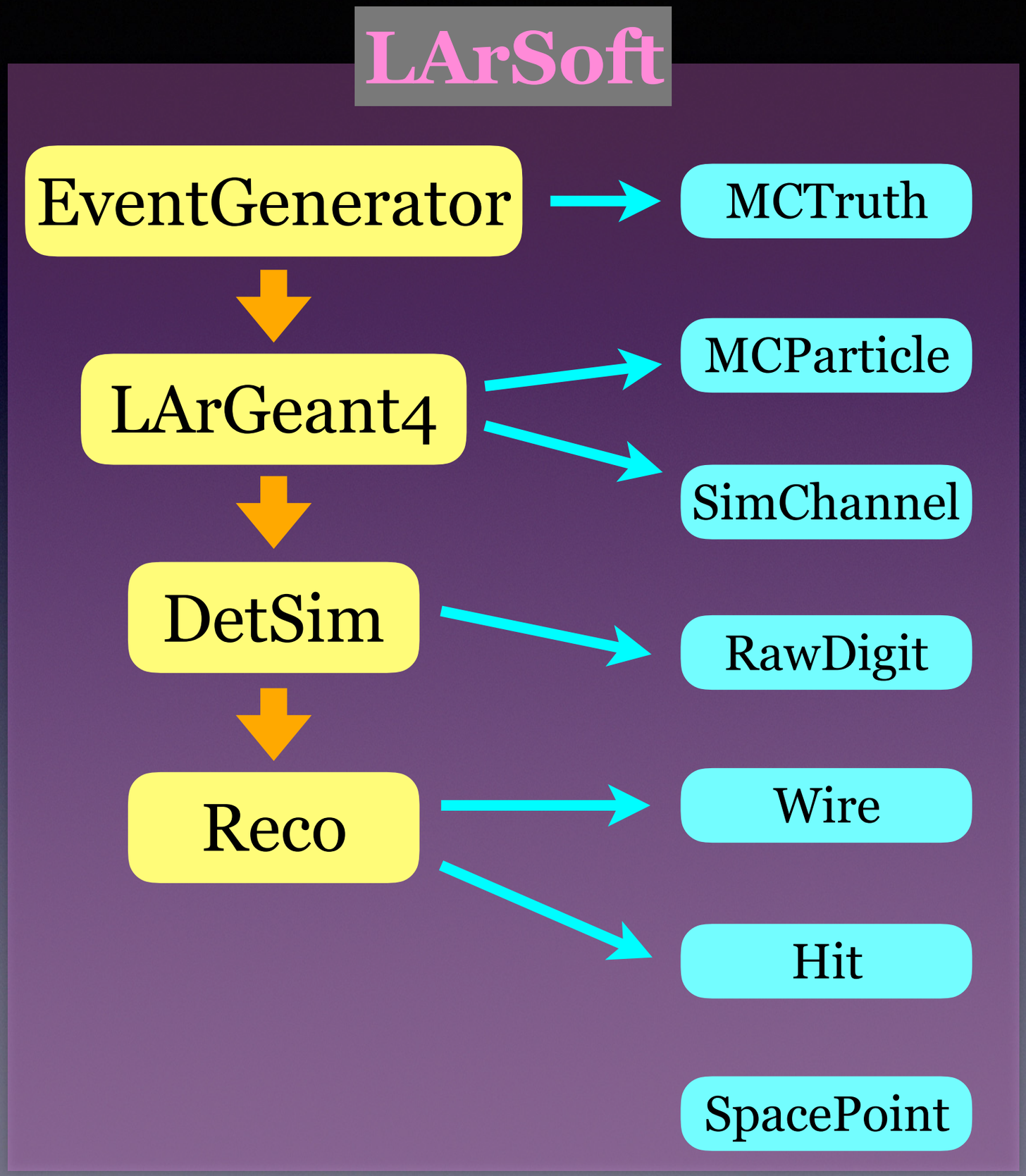
Our Workflow for DNN Research



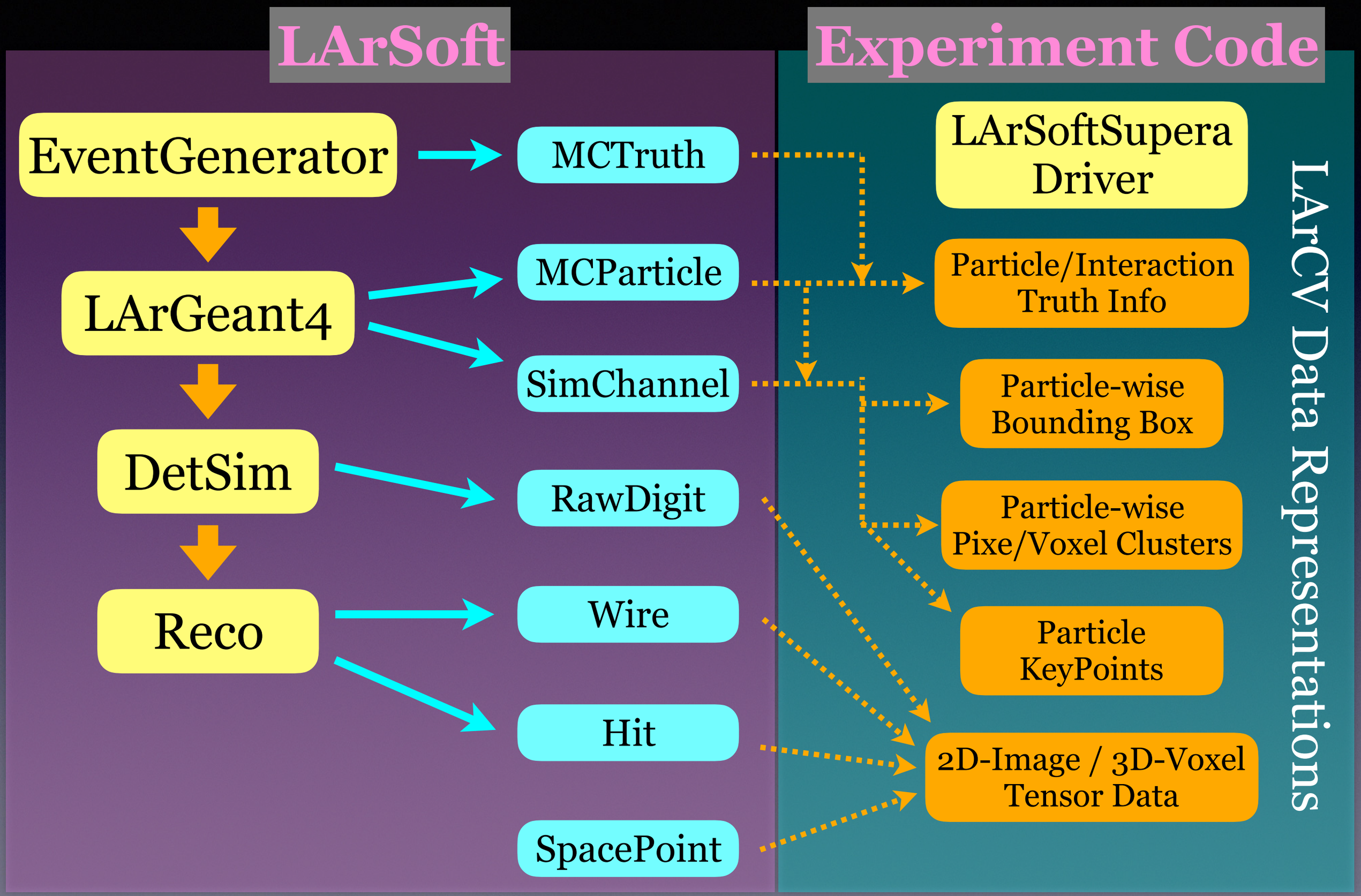
How we interface DNN softwares

- **caffe**: root_data_layer (C++/CUDA) handles CPU/GPU memory buffer copies via LArCV multi-threaded reader
- **Tensorflow**/**PyTorch**: dataloader LArCV python module handles LArCV multi-threaded reader, makes numpy array

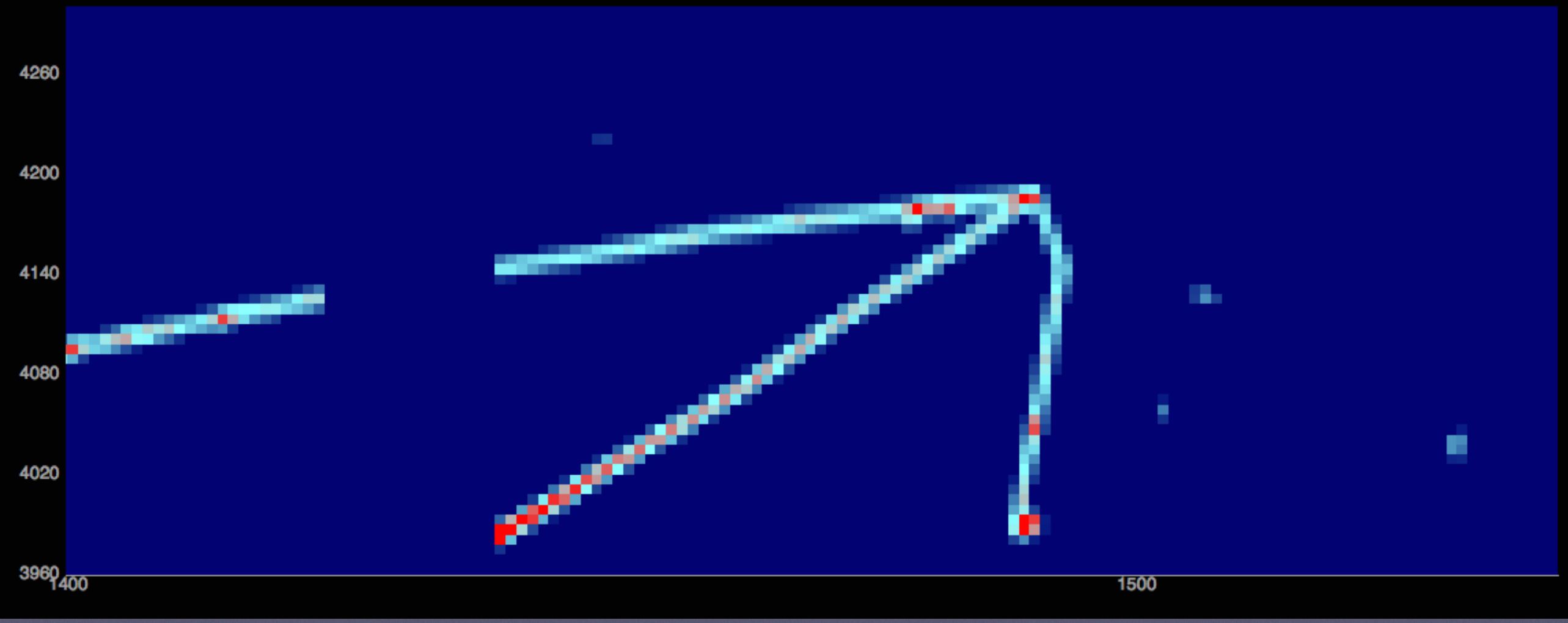
Creating LArCV Data Representations



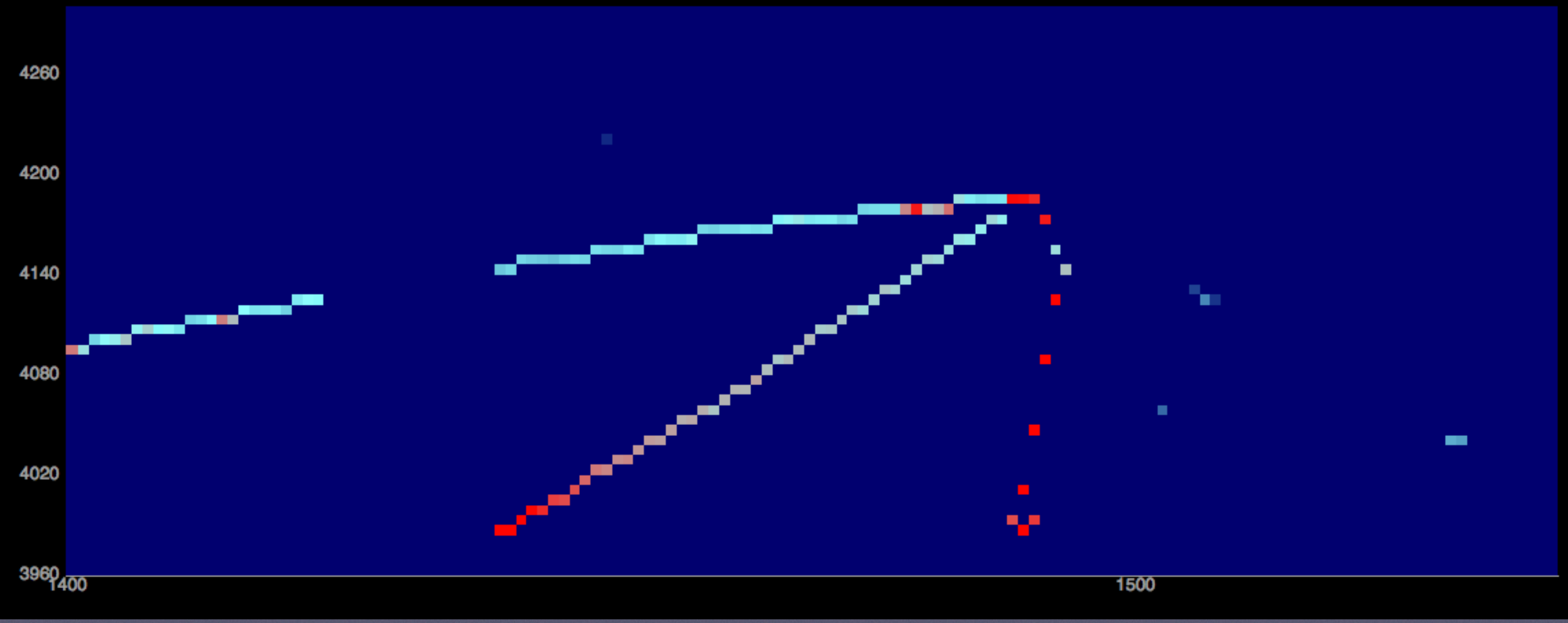
Creating LArCV Data Representations



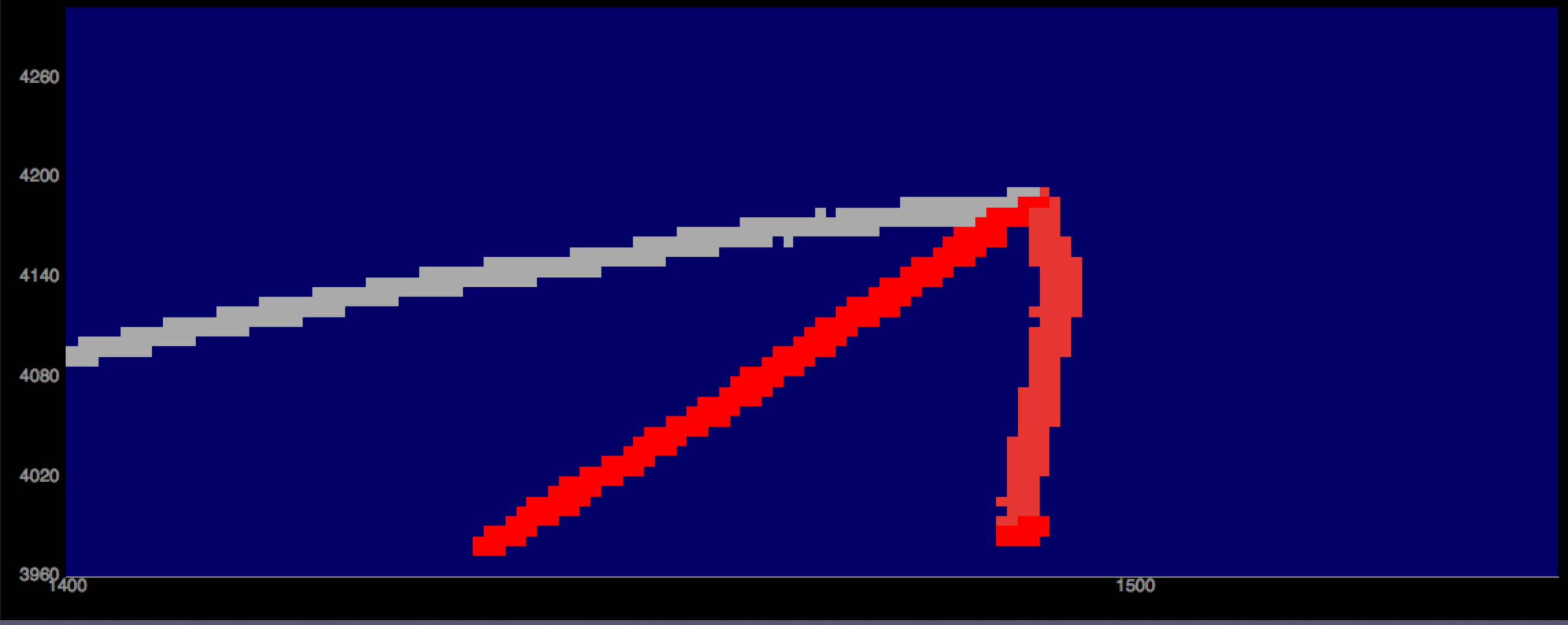
Wire Image



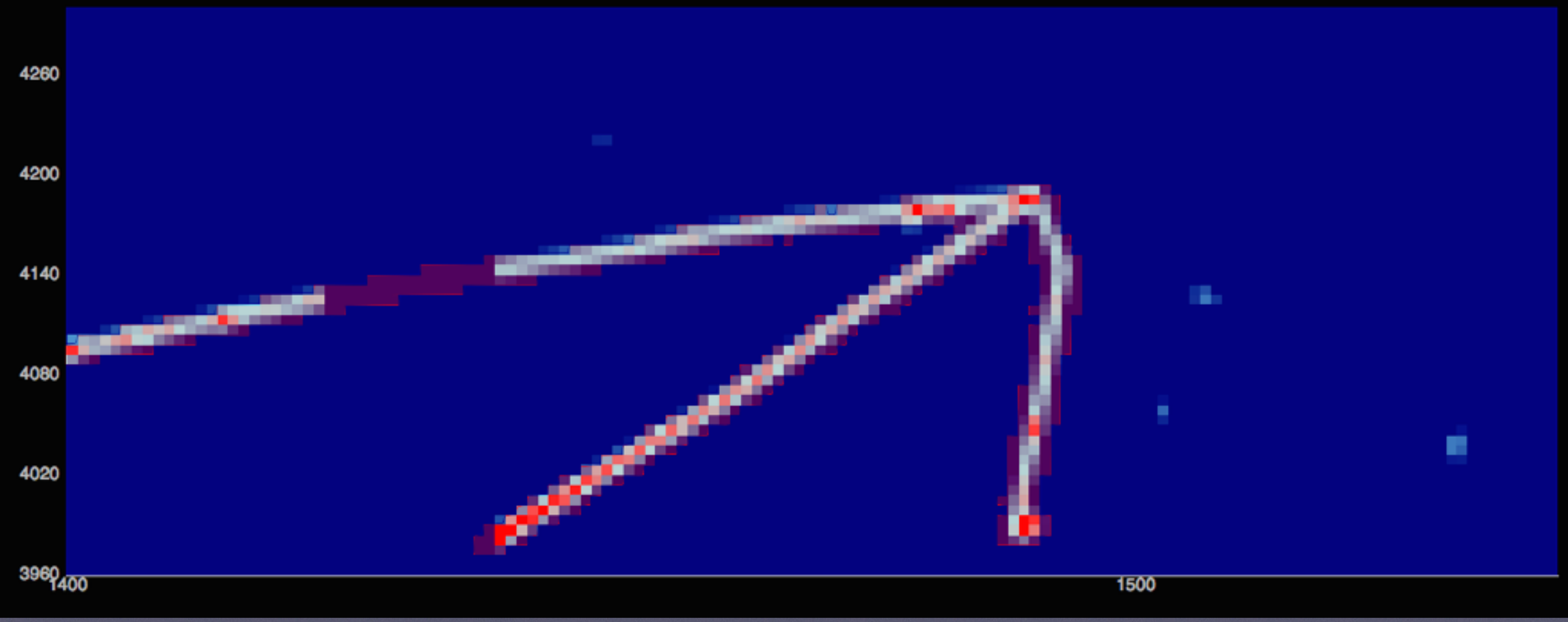
Hit Image



SimChannel

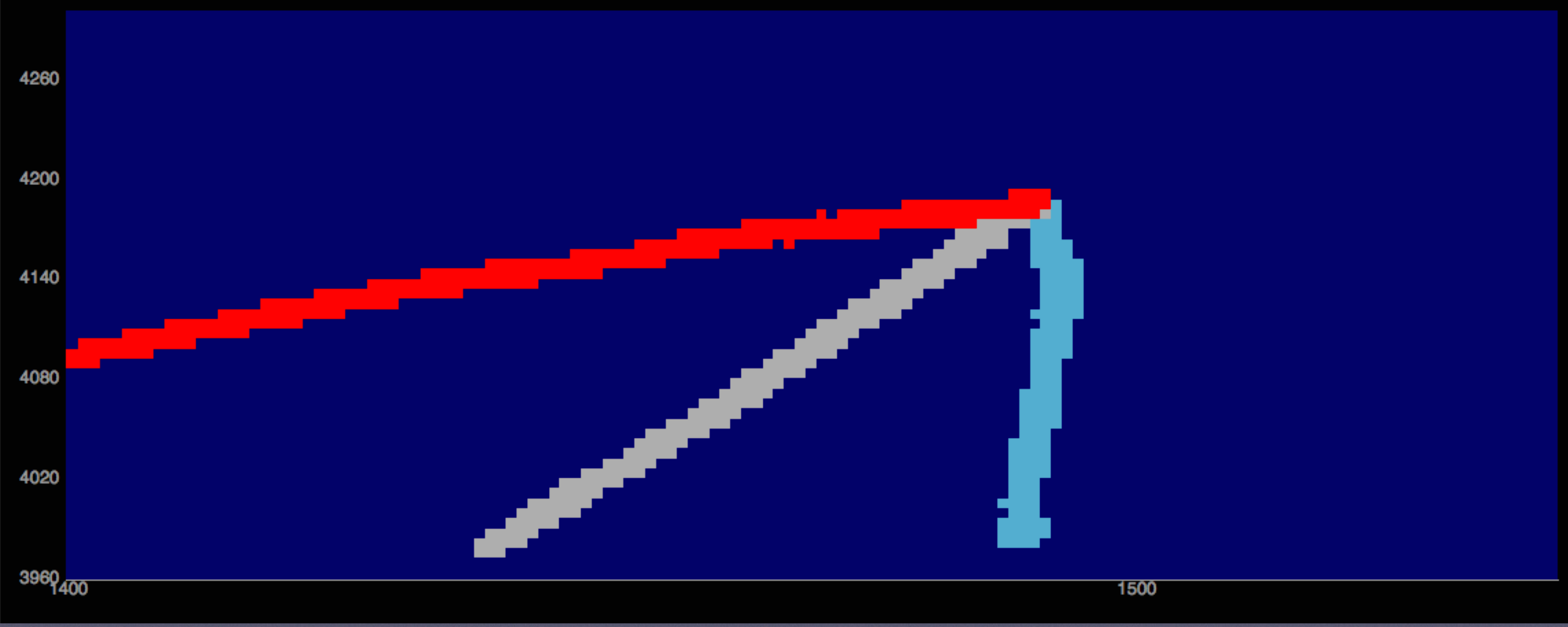


SimChannel + Wire Overlay (cross-check)

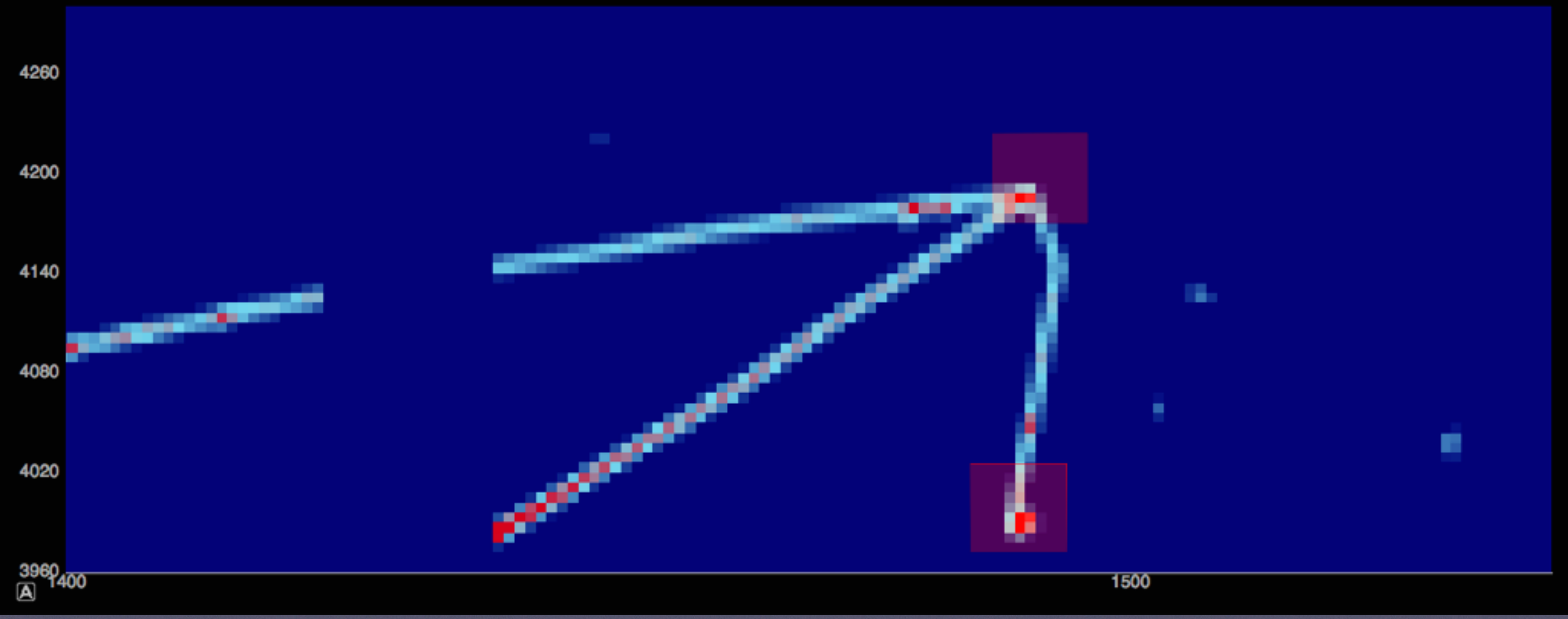


Overlaying regions, makes sense :)

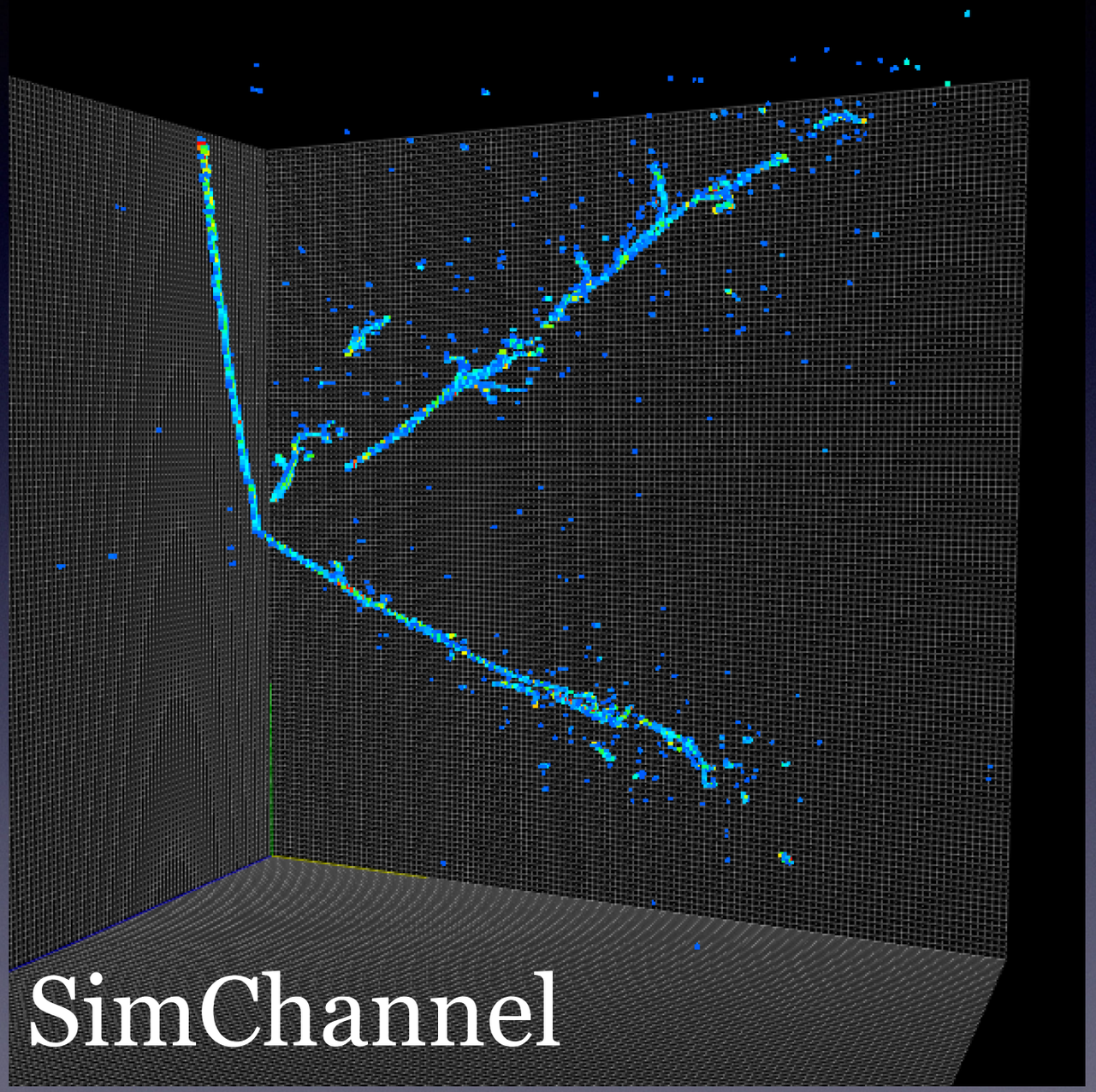
Particle-wise instance labeling

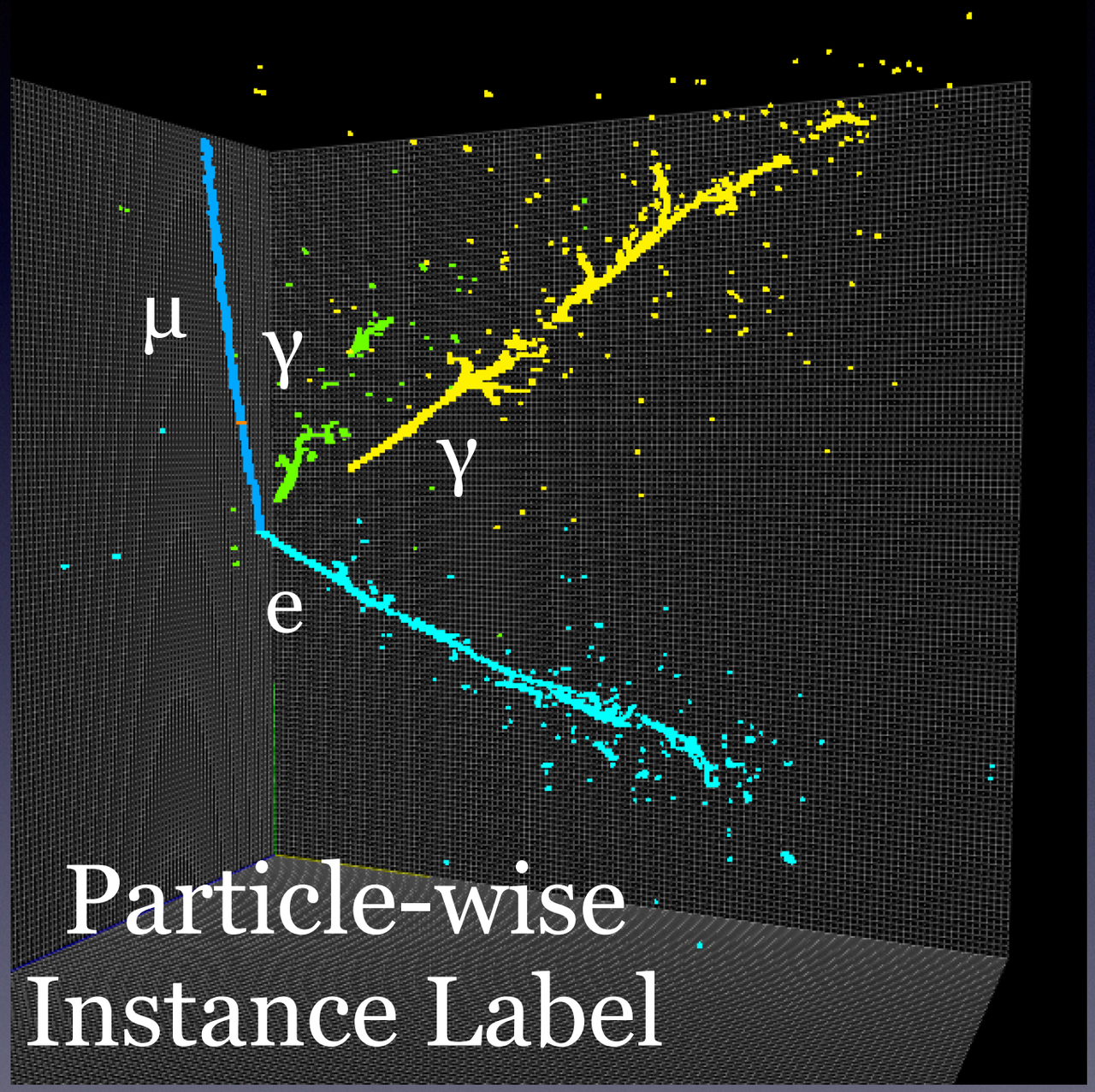


Key point labeling

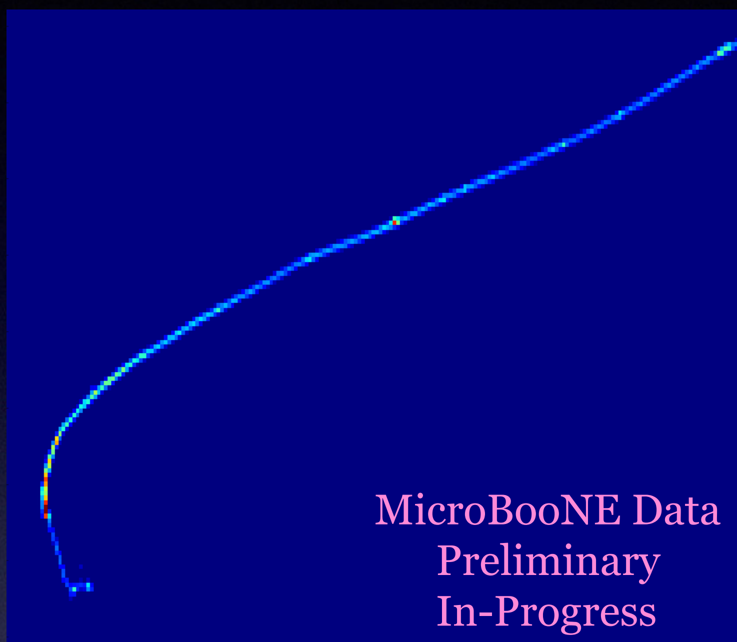


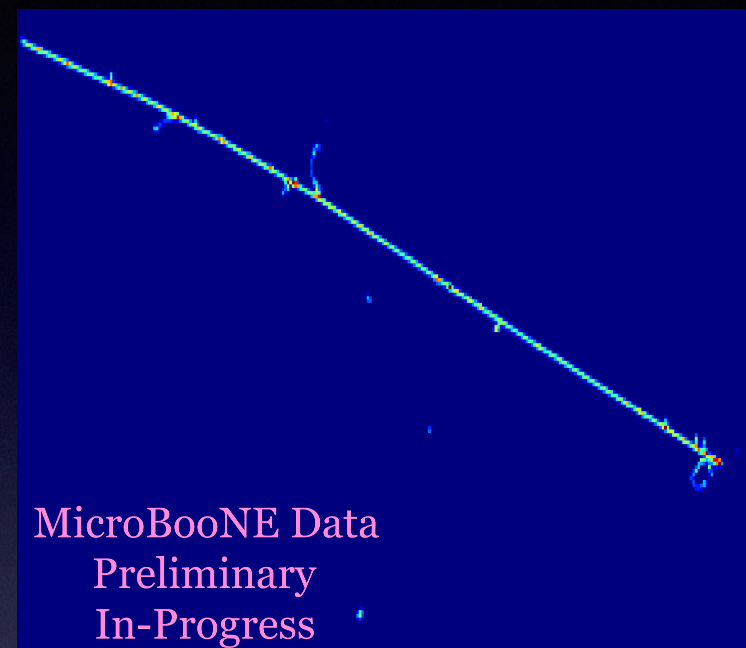
Similarly in 3D

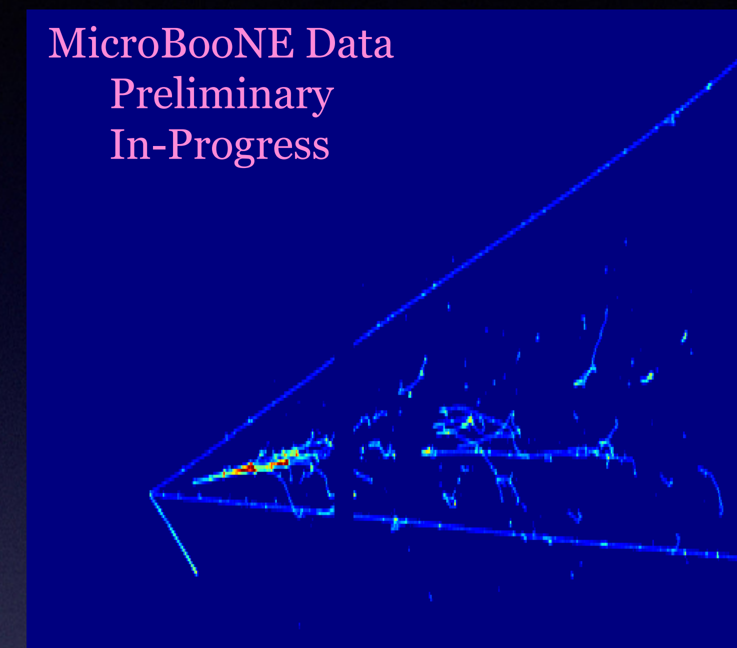


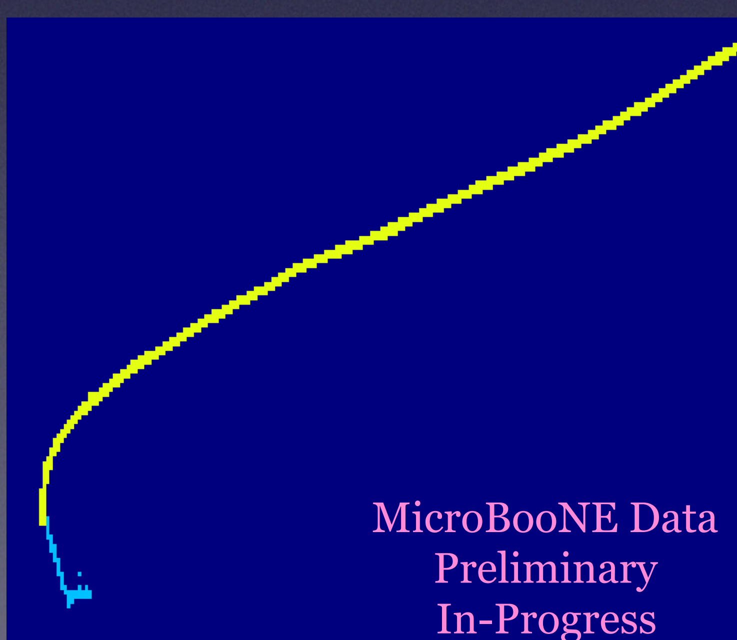


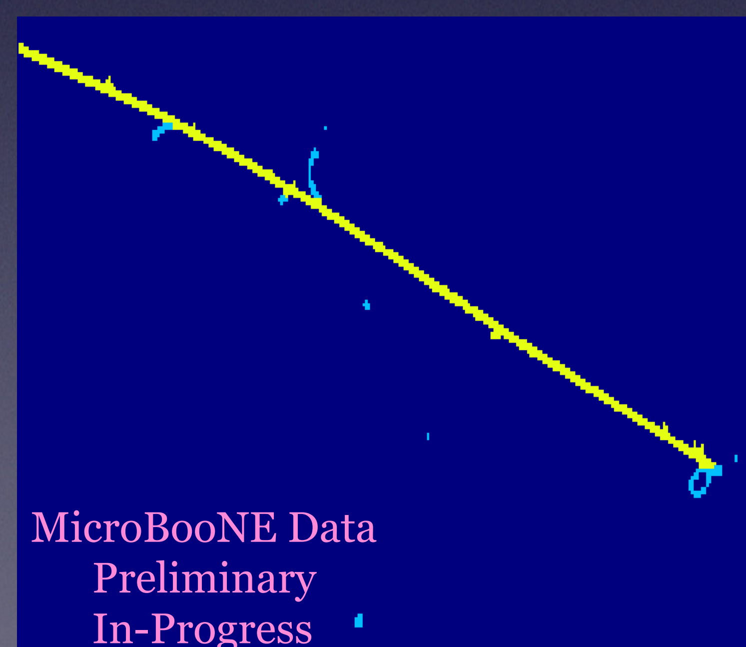
Human-annotation via active LArCV viewer

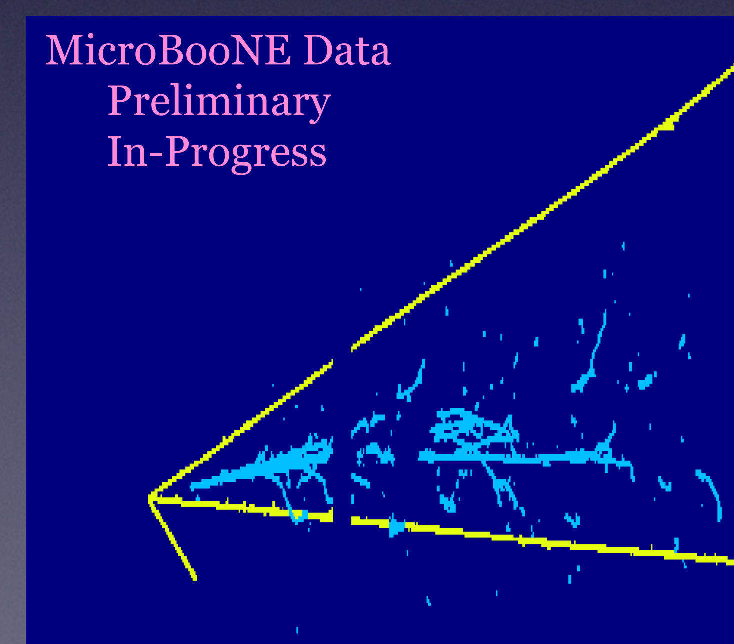






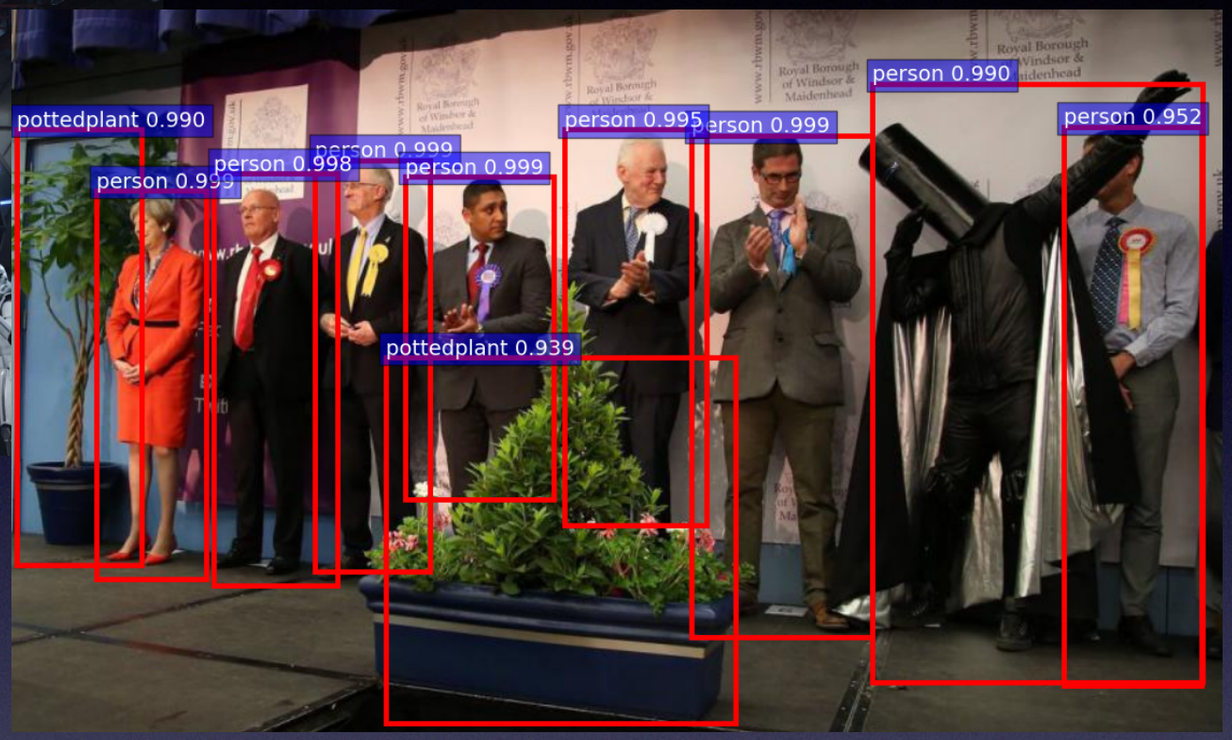






“The empire needs you!”

Detect Lord Buckethead



Outline

- Research focus: LArTPC data reconstruction
- Demonstration of techniques
- Software tools
- **Organization:** where we are, where we are going

Current Development Focus

- **Multi-Particle ID**
  - Model independent final state classifier, wanted by UB
- **3D "smoothing" network**
  - Input: WireCell, Cluster3D, pixel LArTPC
  - Output: ghost removed, better predicted 3D points
- **3D object detection network**
  - Extend Faster R-CNN to 3D, base of instance segmentation
- **2D/3D instance-aware semantic segmentation**
  - particle clustering + PID


Corey
(Harvard)


Kazu
(SLAC)


Taritree
(Tufts)


Ji Won
(Stanford)


Rui An
(IIT)


Samantha
(KSU)

Google Group: **DeepLearnPhysics**

- **Cross-experiment** discussion/development
  - Interests in SBND, ICARUS, MicroBooNE, DUNE ND, ArgonCUBE, NEXT…
- **(Semi-) Weekly meeting** for discussion
- **Organized tutorial** on TensorFlow/LArCV/Network-training in general **using public (toy) LArTPC data**

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DeepLearnPhysics Shared privately

8 of 8 topics (3 unread)

Manage · Members · About

What?
This group is made by experimental physicists to share knowledge/experience beyond the boundaries of existing experiment collaborations.

Who?
The group originated from Liquid Argon Time Projection Chambers (LArTPC) experiments, in particular MicroBooNE (UB) and SBND, but non-LArTPC experimentalists, or non-physicists are certainly welcome to join.

How?
We plan to have a weekly meeting on Wednesday 10AM. We share knowledge, experiences and softwares.
Welcome to the group!

Edit welcome message Clear welcome message

(Bi-)Weekly Meetings (2)
By me - 2 posts - 23 views — Nov 10

Getting started: list of high-level references (papers)
By me - 2 posts - 25 views — Oct 16

For Awesome You Wanting to Help

Software development

- **Singularity container**
  - Can start from old LArCV version, extend to the current one
  - Would be great if QT installation can be included
- **3D Faster R-CNN**
  - 2D version w/ TF available w/ training data
  - Will then extend toward Mask R-CNN
- **3D smoothing network**
  - Can get you high stat data if interested in

... currently most badly wanted/interested in ...

- **3D data annotation via GUI**
  - Extend 2D annotation concept to 3D viewer
- **Decoupling ROOT**
  - Abstract FileIO layer to support different file format
  - Boost (or any other) Python interface (not PyROOT)

μBooNE

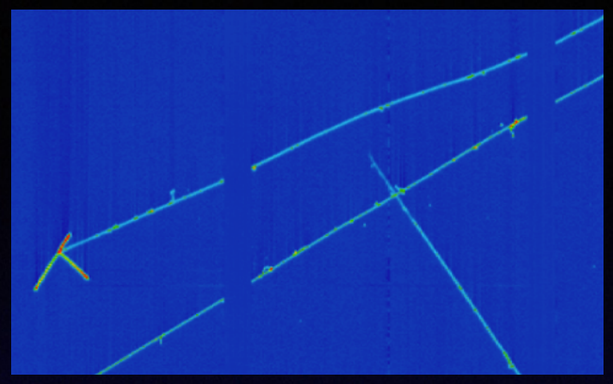
Thank you
for
your attention!

Any Questions

75 cm

Run 3493 Event 41075, October 23rd, 2015

LArTPC Data Reconstruction Path



Waveform

Funding/Job/Ph.D

Publication

Most efficient!

Professor censored looking into this.
He's genius. Not my plan.

MooNet

Takes raw waveform data, generates a paper draft with 5σ new physics result.

MooNet (former SkyNet) will take over the world and we all lose our jobs.